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ECOLOGICAL FACTORS INFLUENCING WHITE-TAILED DEER DAMAGE TO AGRICULTURAL CROPS IN NORTHERN LOWER MICHIGAN

By

Katherine F. Braun

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ABSTRACT

ECOLOGICAL FACTORS INFLUENCING WHITE-TAILED DEER DAMAGE TO AGRICULTURAL CROPS IN NORTHERN LOWER MICHIGAN

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White-tailed deer, *Odocoileous virginianus,* damage to agricultural crops is a persistent issue in Michigan. There is little quantitative information available about the ecological factors that best describe magnitudes and patterns of crop damage. This study was initiated to develop predictive deer crop damage models for selected crops.

Replicated exclosures, paired with areas open to foraging, were used to quantify crop damage in red kidney bean and in alfalfa fields in high and in low deer density areas during 1993 and 1994. Biomass differences were used to estimate production losses. Tart cherry trees were also assessed for damage caused by deer. Percentages of browsed current annual growth twigs on tart cherry trees were determined.

Habitat attributes and quality were assessed within evaluation areas surrounding each crop field and orchard. Evaluation areas were based on the mean daily movement

distance (1.88 km) of radio collared deer.

Deer use of crop fields caused significant production differences in all 4 alfalfa harvests ($P \leq 0.10$). Adjacent wooded, agriculture, and development areas influenced production losses ($P \leq 0.10$). No significant losses were detected beyond 90 m from field edges ($P > 0.10$).

Red kidney bean fields in relatively high deer density areas had statistically significant production losses ($P \leq 0.10$) while low deer density areas did not ($P > 0.10$). Adjacent wooded areas significantly influenced deer use of red kidney bean fields in both deer density areas and significant production losses were detected along development edges in high deer density areas during 1994 ($P \leq 0.10$).

Predictive models for estimating production loss in each crop type were created with field and landscape attributes using stepwise multiple regression ($P \leq 0.15$). Most predictor variables reflected surrounding deer habitat availability and quality. Models can be used to predict potential production loss levels.

Generally, there was less production when there was more wooded area, especially if it was a stand with preferred forage species. There was less crop production when spring food quality was higher in areas surrounding alfalfa fields and in areas surrounding red kidney bean fields in the low deer density area. Red kidney bean fields in the high deer density area had less production when spring food quality was lower. Irrigated red kidney bean fields and fertilized alfalfa fields showed trends of increased crop loss. Hills in fields also showed trends for greater production loss for first alfalfa harvests and for red kidney bean harvests in the high deer density area. Percentages of field perimeters bordered by woodlands impacted patterns of crop loss patterns.

Results elicit patterns and levels of production loss in relation to deer behavior, crop field and growth characteristics, landscape characteristics, deer habitat quality, and land-use practices. Predictive models can be used to estimate magnitudes of potential loss. Patterns of statistically significant losses can be used to predict where losses will occur in agricultural fields. Crop damage control should be proactive. Damage control methods should be decided upon in conjunction with deer habitat quality surrounding crop fields, seasonal deer behavior, local deer densities, crop growth characteristics, and expected levels of damage.

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Richard Long, an extension agent in Presque Isle County, also deserves thanks. He kindly invited me to speak at various functions to let people know about both my research and the other 2 deer damage projects that are being conducted through Michigan State University.

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INTRODUCTION

Michigan's largest white-tailed deer (*Odocoileus virginianus)* population was estimated to be 2 million individuals in 1989 (Michigan Department of Natural Resources Preliminary Report 1991). This large deer population was a result of mild winters in the early 1980's and deer habitat improvement management strategies implemented during the 1970's (T. Carlson, Michigan Department of Natural Resources, pers. commun.). The record size deer herd produced both hunting booms and increased crop damage complaints. While hunters were pleased with the greater number of deer, agricultural producers became upset by the amount of crops they lost to foraging white-tailed deer. As a result, hunters, farmers, and natural resource managers became increasingly polarized with their concerns and opinions, and deer management techniques became the subject of a socio-economic, political, and ecological dispute.

The number of crop damage complaints in Michigan peaked in 1988 and 1989 (T. Carlson, Michigan Department of Natural Resources, pers. commun.). Summer kill permits had been introduced by Michigan's Department of Natural Resources in agricultural areas, but complaints about crop losses persisted. In 1990, the MDNR established block permits, which are used during the regular hunting season for crop damage control purposes, as an additional method for farmers to reduce the impact of deer on their fields. Presently, state biologists can issue both summer kill permits and block permits to farmers within the same year. Shooting permit policies, however, have led to angry hunters, upset farmers, and frustrated biologists because people disagree about the effectiveness of the permit systems in controlling crop damage and the effect shooting permits have on Michigan's deer population (farmers, hunters, and biologists, pers. commun.).

Hunters fear that there will be too few deer to hunt if current shooting permit policies continue, farmers worry there are too many deer, and biologists are concerned about shooting permit abuses and the degree to which farmers are experiencing intolerable crop damage (farmers, hunters, and MDNR biologists, pers. commun.). To add to the complexity of the crop damage issue, tolerance levels for different deer densities and levels of crop damage differ among individuals. A high deer density does not mean the same number to all hunters or farmers, and what one farmer describes as damage another may dismiss as inconsequential loss. Moreover, there is disagreement about whether farmers or the MDNR is responsible for depredating deer. These factors have complicated efforts to agree upon and implement effective solutions to crop damage issues.

Each interest group has legitimate concerns about deer management strategies. Michigan's deer hunting license fees generate $350 million (MDNR Preliminary Report 1994) for the state. Michigan's agricultural producers generate approximately $37 billion for the state, making agriculture Michigan's second leading industry (Michigan Agricultural Statistics 1994). Michigan's economy, its deer herd, and farmers' and hunters' competing interests require that compromises be reached and implemented to foster a stronger state economy and alleviate the strains that exist among farmers, hunters, and natural resource managers regarding deer management.

Presently, there are no ecologically comprehensive descriptions of crop damage patterns and magnitudes in Michigan with which management decisions can be made. Biologists evaluate crop damage using visual assessments of eaten plants in individual crop fields, the estimated number of deer in an area, the number of kill permits that have been issued for the area, and landowners' documented histories of deer damage. As a result, the means of targeting effective control methods are restricted. On a farm by farm basis, summer and block permits are used more than any other method to control deer caused crop damage. The MDNR attempts larger scale deer crop damage control by setting liberal deer harvests during the fall hunting seasons in selected deer management units. To understand crop damage within agricultural landscapes, techniques are needed that consider deer crop damage at a landscape level by accounting for a multitude of ecological factors, in relation to deer demographics, that might be influencing the degree to which deer use croplands. Accurate ecological, economic, and social assessments about deer crop damage could lead to more acceptable compromises for all involved interest groups. An objective assessment of people's perceptions and attitudes about this entire issue would also help to manage the crop damage issue.

To assist with managing Michigan's deer herd and the conflicting objectives of interest groups, information needs to be gathered about the variety of factors that might contribute to crop damage problems. This issue is not a simple matter of deciding how many deer to shoot every year. Rather, deer crop damage is a social and a landscape management problem that requires multi-disciplinary efforts and a landscape perspective to find solutions. Deer densities, landscape characteristics, land-use practices, and the contribution agricultural lands make to deer habitat quality are parts of the landscape in which deer live and are managed by people. The ecological interactions of these factors, in relation to crop loss, need to be assessed and combined into an extensive evaluation of damage so that more comprehensive information and solutions can be used to make deer management decisions. People need to know the ecological elements that influence crop damage and they need to understand that deer are part of a larger habitat than 1 or 2 agricultural fields.

There are many ecological factors that potentially influence deer use of, and damage to, agricultural crops. There are no studies, however, that quantify which combinations of ecological factors best describe different magnitudes of crop loss in Michigan. Deer numbers (Crawford 1984, Halls 1984, Hayne 1984, Vecellio et al. 1994), behavior (Hawkins and Kilmstra 1970, Marchinton and Hirth 1984), movement patterns (Nixon et al. 1991B), food preferences (McCaffery et al. 1974), and seasonal physiological requirements (Mautz 1978) might affect patterns, intensities, and the timing of crop damage. Field morphology could also influence patterns of deer use of fields (Flyger and Thoerig 1962, deCalesta and Schwendeman 1978, Prior 1983, Crawford 1984) depending on the existence and quality of adjacent security cover. Finally, on a larger landscape scale, land-use patterns and the juxtaposition of deer habitat components could influence deer densities in specific areas, movement patterns (e.g. foraging and migration behavior), and the possible development of traditional foraging routes. Consideration of these factors in an investigation of deer caused crop loss can elicit the strongest ecological influences affecting levels of crop loss.

During this study, ecological factors were evaluated with crop loss esitmates and predictive crop loss models were developed. The predictive models reflected that a range of ecological conditions, especially deer habitat quality, influence crop losses. The information from the models make it possible for agricultural producers and biologists to predict potential magnitudes of crop loss so that appropriate action to reduce losses can be taken. Most importantly, the models show that characteristics of the landscape, of which crop fields are a part, strongly influence patterns and magnitudes of crop loss.

This study is part of a larger study. To provide people with quantitative information and objective assessments about deer crop damage issues, Michigan State University undertook a comprehensive and multi-disciplinary project in 1993 entitled "Ecological and Sociological Parameters Influencing White-tailed Deer Damage to Agricultural Crops in Michigan". The results of the first project are presented in this thesis. Dr. Scott Winterstein and Kristie Sitar are directing the second project that is investigating deer movement patterns and habitat use in agricultural landscapes. The third project, directed by Dr. R. Ben Peyton, Dr. Larry Leefers, Peter Fritzell, and Donna Minnis, is addressing the attitudes and perceptions of Michigan farmers and hunters concerning deer crop damage issues and the economic costs associated with damaged crops.

When all 3 studies are completed, the combined information will be available to those interested in learning more about deer crop damage issues. The comprehensive efforts of the project will prompt dialogue among interest groups and contribute to the development of white-tailed deer management techniques that will benefit Michigan's deer herd and Michigan citizens' associated economic and recreational interests.

OBJECTIVES

The objectives of this project were to:

1) Quantify crop loss caused by white-tailed deer to alfalfa, red kidney beans, and tart cherry trees.

2) Assess relationships between crop loss levels in these 3 agricultural crops and deer habitat quality within the study areas.

3) Develop predictive crop loss models for each crop type with production loss estimates in relation to regional deer densities, landscape characteristics, crop field characteristics, crop management practices, and deer habitat quality within the study areas.

4) Make management recommendations to reduce deer crop damage while maintaining deer populations for recreational purposes.

STUDY AREA DESCRIPTIONS

This study was conducted during 1993 and 1994. Individual study sites were located in high and in low deer density areas to test the assumption that crop production losses are greater in relatively high deer density areas than in relatively low deer density areas. Study sites in the high deer density area were located in Alpena, Montmorency, and Presque Isle counties on the northeastern side of Michigan's lower peninsula (Figure 1). Annual deer densities in these areas ranged between 9 and 25 deer per km^2 (T. Carlson, MDNR, pers. commun.). Study sites in the low deer density area were located in Manistee, Benzie, and Leelanau counties on the northwestern side of Michigan's lower peninsula (Figure 1). Annual deer densities averaged 7 deer per km^2 (B. Odom, MDNR, pers. commun.).

These 6 counties have a cool lacustrine climate and relatively long growing seasons because of their proximity to the Great Lakes. The Great Lakes slow spring warming, moderate maximum temperatures throughout the summer months, slow cooling in the autumn, and the lake effects create relatively greater winter snowfalls. The lowest annual temperature usually occurs in February and the highest usually occurs in July. Typical elevational ranges are

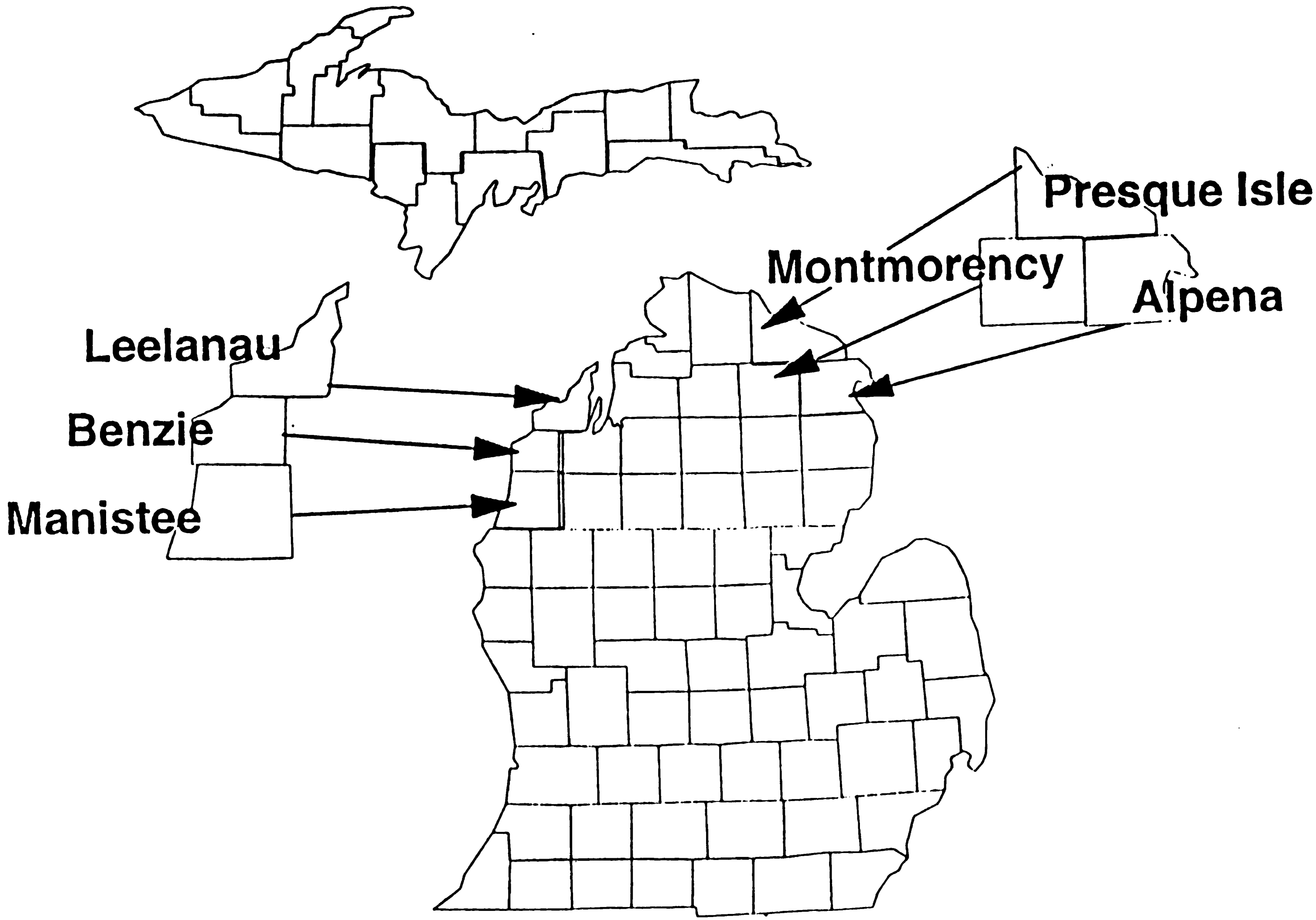

Figure 1. High (eastern counties) and low (western counties) deer density study areas in northern lower Michigan during 1993 and 1994.

176.0 m - 283.0 m so the climate is not much influenced by physiographic features (Albert et al. 1986). Northern hardwoods dominate well drained end-moraine and ground-moraine ridges (*Quercus* species occur only in localized areas) and northern conifers, such as balsam fir (*Abies balsamea*), northern white cedar (*Thuja occidentatlis*), and white spruce (*Picea glauca*) are common (Albert et al. 1986).

Alpena, Presque Isle, and Montmorency counties border each other in the northeastern corner of Michigan's northern lower peninsula. Alpena County's eastern border is Lake Huron. Annual average rainfall is 72.50 cm and average yearly snowfall is 175.0 cm (Eichenlaub et al. 1990). The mean annual temperature in Presque Isle County and Montmorency County is 6.20 C, with the mean temperature from May through September 15.90 C, and the mean annual precipitation is 770.0 mm. Growing seasons in Alpena, Montmorency, and Presque Isle counties range from approximately 108-126 days with the more inland areas being towards the lower end of the range (Albert et al. 1986).

Manistee, Benzie, and Leelanau counties are located on the northwestern side of Michigan's northern lower peninsula. Leelanau County forms a peninsular area in Lake Michigan and Grand Traverse Bay with Benzie directly south and Manistee directly south of Benzie. The approximate average yearly temperature ranges from 6.70 C to 7.80 C. The growing season ranges from 125-141 days with the longer season in areas along the lakeshore. Elevations range from 212.0-364.0 m (Albert et al. 1986).

In Alpena, Presque Isle, and Montmorency counties, soils are characterized by drumlins and moderately sloping ground moraine with some sandy lake plain and limestone areas. Leelanau County soils are composed of ground rock material consisting of clay, loams, sand, and gravel types (Weber 1973). The eastern regions of Manistee and Benzie counties have well drained sandy outwash plains. The more western areas are characterized by lake plain and ground moraines (Albert et al. 1986).

Alpena, Montmorency, and Presque Isle Counties are composed of a mixture of agricultural lands and other land ownership types. The area has high to medium potato production, medium hay and alfalfa production, and low corn, bean, and fruit production. Red kidney bean production is relatively low, but the beans that are grown produce high quality seed beans (Dudderar et al. 1989). Most of these 3 counties are forested and white spruce, balsam fir, and northern white cedar are prevalent throughout the area. Outwash deposits and relatively level ground moraine areas support tamarack (*Larix laricina*), quaking aspen (*Populus tremuloides*), and northern white cedar, black ash (*Fraxinus nigra*), balsam poplar (*Populus balsamifera*), and speckled alder (*Alnus rugosa*) (Albert et al. 1986).

Manistee, Benzie, and Leelanau counties have high fruit tree production, medium to low hay production, low bean and corn production, and some Christmas tree production (Dudderar et al. 1989). Black oak, white oak, and jack pine (*Pinus banksiana*) are common species growing in the well drained outwash plains in the eastern regions of Manistee and Benzie counties. The western parts of the counties more commonly have northern hardwoods growing in the medium and coarse textured moraines (Albert et al. 1986).

A total of 36 alfalfa, 35 red kidney bean, and 5 tart cherry orchards were used in this study. All 36 alfalfa fields and 20 of the 35 red kidney bean fields were located in Alpena, Montmorency, and Presque Isle counties. All 5 orchards were located in Manistee, Benzie, and Leelanau counties and 15 red kidney bean fields were located in Manistee County.

METHODS

Crop Loss Estimation

Alfalfa, red kidney beans, and tart cherries were identified by MDNR biologists as crops that received a high number of deer damage complaints. Thirty-seven agricultural producers who planted 1 or more of the 3 chosen crops were identified either from MDNR records of farms that had reported deer crop damage in the past or from asking farmers in the area to participate in the study. Alfalfa fields and red kidney bean fields were chosen either randomly from a pool of each landowner's fields, or fields were chosen based on location or planting date to minimize traveling and scheduling constraints. Field boundaries used in this study were those established by landowners.

Twenty red kidney bean fields and all 36 alfalfa fields were located in Alpena, Montmorency, and Presque Isle counties (Table 1). All 15 red kidney bean fields in the low deer density area were located in Manistee County because of the limited number of landowners growing red kidney beans in this region. The 5 tart cherry orchards were located in the 3 western counties. Field size ranged from 1.62-48.60 ha and sections of orchards used in this

Table 1. Sample size of fields and orchards for each crop type used in 1993 and 1994 for estimating deer-caused crop losses in northern lower Michigan.

Crop type	1993	1994	Totals
Alfalfa	16	20	36
Red kidney beans	18	17	35
Tart cherries	4	5	5
Totals	38	42	76

study ranged from 4.05-36.45 ha.

Information was collected from a total of 71 fields and 5 orchards (Table 1). The 71 fields were harvested 99 times and data was collected prior to each of those 99 harvests. Alfalfa samples were collected prior to 64 alfalfa harvests from the 36 fields; 31 first harvests and 33 second harvests. Bean samples were collected prior to 35 red kidney bean harvests from the 35 fields; 20 in the high deer density area and 15 in the low deer density area. Percentages of browsed current annual growth twigs were collected from 5 tart cherry orchards.

There were 664 paired samples collected prior to the 64 alfalfa harvests (Table 2). There were 355 paired samples collected from the 35 red kidney bean fields in the high and the low deer density areas (Table 3).

Exclosures (2.0 m x 2.0 m x 1.5 m) were used to quantify production differences between exclosed areas and areas open to foraging. Each field had a maximum of 11

Table 2. Number of paired samples collected prior to first and second alfalfa harvests during 1993 and 1994 in northern lower Michigan.

Harvest	1993	1994	Total
1st harvest	117	202	319
2nd harvest	170	175	345
Totals	287	377	664

Table 3. Number of paired samples collected prior to each red kidney bean harvest in the high and the low deer density areas during 1993 and 1994 in northern lower Michigan.

Deer density	1993	1994	Total
High density	101	105	206
Low density	77	72	149
Totals	178	177	355

exclosures and a minimum of 9. Exclosures were proportionally stratified among a core area and 3 possible edge types surrounding each field: wooded, agriculture, and development. The development category included houses, barns, paved roads, and active livestock pastures. These categorical divisions were used to determine if adjacent land-use influenced crop loss patterns in fields.

Every field was mapped to determine its size, shape, perimeter length, and proportion of each of the 3 edge types present. A 180.0 m distance was used to determine if a field was large enough to have a core area. The 180.0 m distance refers to the distance within which deer will usually stay between foraging areas and security cover areas (Bender and Haufler, unpubl.). In "A White-tailed Deer Habitat Suitability Index for the Upper Great Lakes Region" (Bender and Haufler, unpubl.), an optimal suitability index of 1.0 was given to openings or fields that were $\leq$ 180.0 m wide. Suitability indices decreased to a 0.25 minimum as the width of openings increased to 360.0 m and greater.

A zone was measured from the edge of each field to 90.0 m into each field (perpendicular to the field edge). Any area of a field that was > 90.0 m from an edge was classified as the core area. Two exclosures were constructed in the core area for each field that had a core area. Eleven exclosures were built in fields that had a core area and 9 exclosures were built in fields that had no core area.

Core area exclosures were built in random locations within the core areas. The remaining 9 exclosures were divided proportionally among the edge categories surrounding each crop field. For each edge category, the proportionally allotted number of exclosures were built in randomly selected locations within the 90.0 m zone between field edges and core areas. Each non-core exclosure was located using a random direction and a random number of paces from the exclosure preceding it until the 90.0 m zone adjacent to each edge category bordering a field contained its proportionally allotted number of exclosures. For fields with no core area, the 9 exclosures were proportionally divided among edge categories starting from a randomly chosen point in field. Ten exclosures were used on fields that had a core area and 2 edge categories that were proportionally equal to each other.

Each exclosure was constructed with four 1.5 m steel-t posts and 8.0 m of Tenax C-flex polyproplene fencing that had 5.63 cm x 6.89 cm mesh openings (Construction Supply, Inc., Highland, Mich). The selected mesh size was used to minimize shading and moisture retention. Exclosures were constructed from May 1 - 15, 1993 and April 1 - 26, 1994 in alfalfa fields and during June of 1993 and 1994, 1 to 4 days after planting, in red kidney bean fields.

Red kidney bean fields were cultivated 2 or 3 times per summer during June and early to mid-July. Exclosures were rolled up and moved out of the machinery's way for each cultivation. The southeast corner plant in each exclosure was flagged to mark each exclosure's location during cultivation. Exclosures were rebuilt around the plants immediately following cultivation.

A 1.0 m^2 plot was harvested from the middle of each exclosure, leaving a 0.5 m buffer area around each plot to avoid any enhanced growth caused by the presence of exclosure fencing. Each 1.0 m^2 plot that was open to foraging was located 10.0 m in a random direction from each exclosure. A 10.0 m distance from every exclosure was chosen to avoid biases associated with deer being attracted to exclosures and also to minimize the variability associated with collecting paired samples from farther areas of the field where growing conditions might have been different.

Alfalfa fields were harvested 1 or 2 times between June and September of each year. Paired samples were collected as close as possible to the time landowners harvested their fields. Exclosures were removed from fields and rebuilt in their original location immediately following a field's first harvest. Time and logistic constraints prevented gathering data on more than 2 harvests per field (many fields had 3 harvests during a growing season).

Alfalfa samples were collected between 1 June and 4 July, during 1993 and 1994 for the first harvests and between 20 July and 18 August, 1993 and 20 July and 11 September, 1994 for the second harvests. Alfalfa was cut with grass shears to the approximate height that it was to be harvested (usually 2.54 cm-7.62 cm) and placed into brown paper bags. Bags and their contents were air dried and later dried in a laboratory drying oven for a minimum of 24 hours at 60 C and weighed to the nearest 0.01 g.

Red kidney bean samples were collected between 3 September and 10 October during both 1993 and 1994. Pods were pulled off plants by hand and placed in brown paper bags. Beans were shelled and culled by hand to approximate landowners' marketable yields. Shelled and culled red kidney bean samples were tested for moisture content and weighed to the nearest 0.01 g and a final weight was calculated for a marketable 15% moisture level using a digital moisture tester and the following equation (S. Elias, Mich. State Univ., Crop and Soil Sciences, pers. commun.):

[sample weight * (100-sample's moisture content)]/85

Statistically significant paired plot production differences are referred to as being from a particular harvest. Production in open and in exclosed areas were averaged for individual fields. The mean production in open and exclosed areas for each field were then combined to get overall mean production in open and in exclosed areas for each harvest. These overall averages were used to test for statistically significant differences between open and exclosed areas.

Cherry orchards did not require exclosure construction. Orchards were located that had some cherry blocks (blocks are planted sections of orchards that predominantly have the same age trees) open to browsing and other blocks surrounded by high-tensile electric fence. Five tart cherry orchards were selected in the 3 western counties based on the presence of fenced and unfenced tart cherry orchards. Except in 1 orchard, the selected fenced and unfenced blocks were not adjacent to each other. The 1 orchard that had the fenced and unfenced area next to each other had approximately 30.0 m between the fenced block and the unfenced block. Therefore, deer movement along the side of the unfenced block closest to the fenced block was not prevented by the fencing.

One-hundred trees in areas open to browsing in each orchard were assessed for deer browsing on current annual growth (CAG) twigs. Four orchards were used during 1993 (total number of trees assessed = 400) and 5 orchards were used during 1994 (total number of trees assessed = 500). Trees $\leq$ 8 years old were used because younger developing trees have their growth and production potential impacted more by deer browsing than do older (> 8 years old) trees (orchardists, pers. comm.). If a fenced block had predominantly younger trees (1-4 years) or older trees (5-8 years) instead of a mix of all ages between 1 and 8 years, then unfenced blocks with similar ages were paired with the fenced area so that information was associated with trees at similar growth stages.

Browsed CAG twigs were counted during the final week in July, 1 day to 1 week prior to harvest, during 1993 and 1994. Trees within fenced areas were assumed to have no browsing and they were not individually assessed for browsing. Trees sampled in areas that were open to browsing were chosen randomly by selecting random rows and random trees within rows. The number of browsed CAG twigs were counted from the ground to 2.0 m high.

For each tree, the percentage of browsed CAG twigs was calculated by dividing the number of browsed CAG twigs by the number of CAG twigs present on the tree from the ground to 2.0 m high. For older or fuller growing trees, percentages of browsed CAG twigs were calculated from the first 200 CAG twigs encountered. An average percentage of browsed CAG twigs was calculated for the area open to browsing in each orchard.

During 1994, a component was added in an attempt to obtain production differences between areas open to browsing and fenced areas. This component involved determining how deer browsing on buds affected the number of cherries produced. In the 4 orchards that were used in the study during 1993, trees were randomly selected by row and one 1.27 cm-2.54 cm diameter branch, between 0-2.0 m from the ground, was selected on each tree. Each randomly chosen branch was flagged and every bud on that branch was counted. Buds were counted during the time of flowering (late May) on 50 trees in fenced areas and on 50 trees in areas open to browsing. During the last week in July, the number of cherries produced on each flagged branch was counted. The percentage of buds that produced cherries on each flagged branch was calculated by dividing the number of cherries produced by the number of buds. An average percentage of cherry production was calculated for each fenced area and for each area open to browsing. The two percentages were then compared. The potential effects of deer browsing are discussed later in this thesis and monetary value associated with tree growth until production age is reached is referenced in Appendix A.

Landscape Characteristics

Vegetation Sampling

Vegetation types and development adjacent to crop fields were classified and recorded. Agricultural fields that were adjacent to fields with exclosures were classified by crop types that were planted during 1993 and 1994. Wooded areas were evaluated based on vegetation parameters described in "A White-tailed Deer Habitat Suitability Index Model for the Upper Great Lakes Region" (Bender and Haufler, unpubl.) (Appendix B). The habitat suitability index model (HSI) model has variables that are divided into 4 sub-models (Table 4).

Vegetation characteristics in wooded areas around each agricultural field and each orchard that was open to browsing were sampled using randomly located belt transects. Transects were placed within 200.0 m of edges between crop fields and woodlands because deer tend to use security cover within 183.0 m from the edge of foraging areas and into security cover areas (Bender and Haufler, unpubl.). Transects were completed in the nearest wooded area when fields had no wooded area directly adjacent to them (4.2% of fields were not directly adjacent to wooded areas and 100.0 m was the farthest distance a wooded area was from a field).

Table 4. White-tailed deer HSI sub-model variables (Bender and Haufler, unpubl.).

Sub-model	Variable description
Fall/winter food	woody stem density/ha
	red pine site index
	basal area of oaks (m^2/ha)
	species diversity of oaks
	oak species mean dbh (cm)
	maximum crop field width
	crop species cultivated
	crop management practices
	% evaluation area in fall winter foods
Spring food	maximum crop field or opening width
	total herbaceous productivity
	crop species cultivated
	% forest ground cover
Security cover	shrub/sapling density/ha
	mature stand density vs. size cover relationship (trees/ha vs. BA/ha)
	% evaluation area in security cover types
Thermal cover	distance to thermal cover
	% conifer canopy closure
	northern white cedar site index
	conifer stand size
	total conifer basal area (m^2/ha)
	dominant overstory conifer species

Vertical cover was measured in 3 height strata using the line intercept technique (Higgins et al. 1994): 0-1.5 m, 1.5 m - 7.0 m, and > 7.0 m. Percent conifer cover was recorded as a subclass of overall vertical cover. Horizontal cover was measured with a profile board (Gysel and Lyon 1980) and height classes were 0-0.5 m, 0.5 m - 1.0 m, 1.0 m-1.5 m, 1.5 m-2.0 m. Woody stems rooted within transect boundaries were counted and recorded by species. Diameter at breast height (dbh) was recorded for trees $\geq$ 10.0 cm dbh. Any woody stems $\leq$ 10.0 cm dbh were counted in the shrub and sapling category.

Sub-model habitat suitability indices were calculated for areas surrounding each field and each orchard that was open to foraging. Values of 1.0 represented relatively high deer habitat conditions and 0.0 represented relatively poor deer habitat conditions. The overall HSI value for an area was equal to the lowest sub-model HSI value.

Any deer signs such as trails, pellets, tracks, and beds were also recorded. Dates and times were recorded for deer sightings in wooded areas and in agricultural fields used in the study. Notes were also taken on deer feed plots, piles, or baits that were noticed along transects or in crop fields or along field borders.

Landscape Attributes and Habitat Quality Quantification

Spatial analyses of landscape attributes and variables associated with deer habitat quality that might have influenced crop loss patterns and intensities were conducted using the geographic information system (GIS) PC ARC/INFO 3.4D (Environmental Systems Research Institute, Redlands, Calif. 1989). An evaluation area was created around each field and each orchard by mapping each field's or orchard's outline in the proper PC ARC/INFO township coverage. Field and orchard borders were based on MDNR 1987 air photographs and hand-drawn field maps. Land-use coverages used for evaluation area analyses were digitized by MDNR personnel from 1979 air photographs and labeled with Michigan Inventory Resource System (MIRIS) codes.

Evaluation area size was based on the mean daily movement distance (1.88 km) of radio-collared deer in Presque Isle and Montmorency counties (K. Sitar, Mich. State Univ., pers. commun.). The mean movement distance was used as a radius that extended around the centerpoint of each orchard and each crop field that had exclosures built on it. For example, the black dot in the center of the evaluation area in Figure 2 represents the center of a field for which surrounding habitat was evaluated. Evaluation area size was 11.1 km^2. Vegetation characteristics and habitat quality indices were then calculated for each evaluation

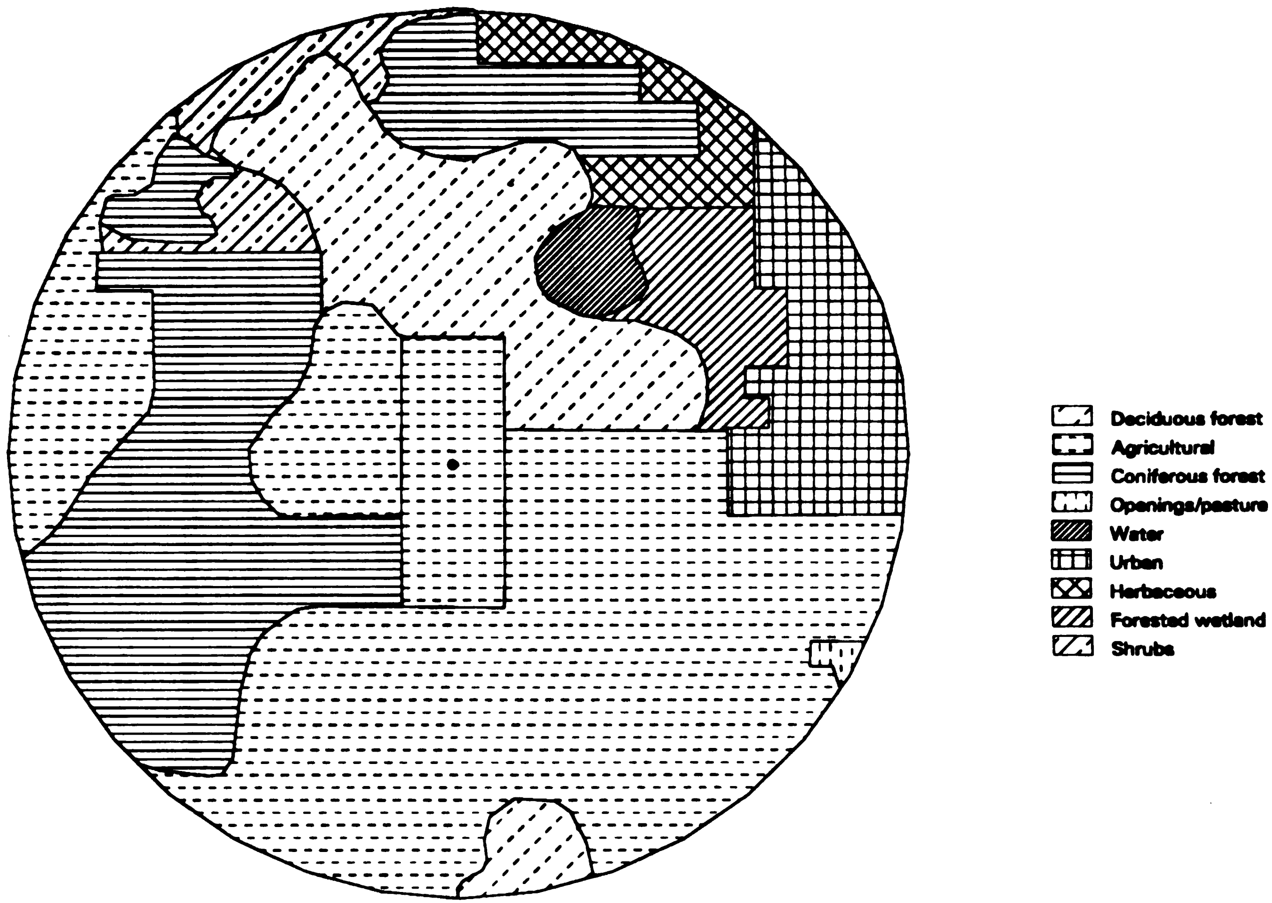

Figure 2. Evaluation area example (11.1 km^2) for agricultural areas in northern lower Michigan.

area.

Field and landscape characteristics were quantified within evaluation areas (Tables 5 and 6). These variables were used to identify the most influential ecological factors that affected deer caused crop loss so that predictive crop loss models could be developed for each crop type.

Field and landscape variables quantified with PC ARC/INFO were: areas of different vegetation types, perimeter lengths of different vegetation types, proportion of the area of different vegetation types to agricultural area, and distance measures. Edge diversity indices were calculated (Patton 1975) from area and perimeter length information generated by PC ARC/INFO.

Forested, agricultural, and open areas were delineated using MIRIS classifications. Vegetation types were divided into 8 categories (Appendix C). Agriculture, openings, woodlands were used as 3 categories. The woodland category was further divided into 5 categories based on MIRIS codes: upland hardwood, lowland hardwood, aspen and birch, pine and upland conifers, and lowland conifers. Within evaluation areas, the 8 categories were used to assess characteristics associated with different vegetation types within evaluation area landscapes.

Information about individual land-use practices within evaluation areas was gathered from conversations with landowners and with a standardized telephone survey

Table 5. Field variables that were examined for their influence on crop loss levels in northern lower Michigan during 1993 and 1994.

Variables
field size (ha)
field perimeter length (m)
presence of hill(s) in fields (yes/no)
% of field perimeter adjacent to agriculture
% of field perimeter adjacent to woodlands
% of field perimeter adjacent to development
number of years field has been seeded
seed variety
fertilizer used (yes/no)
herbicide used (yes/no)
pesticide used (yes/no)
number of days exclosures were in field
number of deer sighted in field
% summer shooting permits used
% block permits used
control method(s) used

Table 6. Landscape variables that were examined for their influence on crop loss levels in northern lower Michigan during 1993 and 1994.

Variables
amount of precipitation
supplemental feeding
general geographic field location
road type: *highway, dirt*
area (ha) of different vegetation types within evaluation areas: *agriculture, all wooded types combined, openings, upland hardwoods, lowland hardwoods, aspen and birch, pine and upland conifers, and lowland conifers*
perimeter length (m) of different vegetation types in evaluation areas: *agriculture, all wooded types combined, openings, upland hardwoods, lowland hardwoods, aspen and birch, pine and upland conifers, and lowland conifers*
edge diversity index (Patton 1975) for different vegetation types in evaluation areas: *agriculture, all wooded types combined, openings, upland hardwoods, lowland hardwoods, aspen and birch, pine and upland conifers, and lowland conifers*
ratio of the area of different vegetation types to agricultural areas within evaluation areas: *all wooded types combined, openings, upland hardwoods, lowland hardwoods, aspen and birch, pine and upland conifers, and lowland conifers*
HSI values: *HSI fall/winter food, HSI spring food, HSI security cover*
SI values: *SI forest, SI open, SI agriculture for fall and winter food, SI agriculture for spring food, SI security cover with agriculture component*
vegetation characteristics: *stem density (per ha), basal area (m^2/ha), mean horizontal cover, mean vertical cover*
distance to nearest: *thermal cover stand, hunt club, and house, barn, or livestock pasture*

(Appendix D). Land-use information consisted of tillage practices, pesticide, fertilizer, and herbicide use, planting or seeding schedule, seed variety planted and any deer control methods that were currently being used, such as summer shooting permits or block permits, lure crops, scent deterrents, or scare devices. The number of summer shooting permits and block permits issued by the MDNR and the number of permits used by landowners were collected from MDNR biologists (T. Carlson, Atlanta and B. Odom, Traverse City). Percentages of permits used were calculated and tested for correlations with crop loss levels.

Precipitation information was gathered from climatological records from weather stations that were closest to fields being used in this study (NOAA Michigan Summary 1993 and 1994). Orchards and fields were grouped by general geographic location so that climatological information from the closest weather station could be used to quantify influences precipitation levels might have had on deer-caused crop production losses. Precipitation totals for each month were added for the months during which crops grew before being harvested so that precipitation levels were field-specific with respect to when each field was harvested.

Many of the field and landscape variables were categorical. Categorical variables were: presence of hills in fields, geographic field location, fertilizer use, fertilizer type, herbicide use, pesticide use, seed variety, irrigation frequency, supplemental feeding plot or lure crop use, crop damage control methods, and road type nearest to fields. Data related to the remaining variables were continuous (Tables 5 and 6).

HSI Model Program in GIS PC ARC/INFO

The HSI model for the Upper Great Lakes Region (Bender and Haufler, unpub.) was programmed into PC ARC/INFO so that individual sub-model HSI's and suitability indices (SI's) could be calculated for each evaluation area. This HSI program in PC ARC/INFO gave users the capacity to manipulate land-use delineations so that various land-use scenarios can be evaluated. Many of the SI's were used to illustrate the overall contribution of agricultural land to deer habitat quality and the relative quality of various landscapes for supporting deer.

Habitat suitability indices were generated for each field or orchard. Spatial HSI model variables, such as forested area, agricultural area, and distance to the nearest thermal cover stand $\geq$ 2.0 ha, were calculated by the HSI program in PC ARC/INFO. The HSI program was used to calculate maximum field width, but maximum field width was not readily apparent in many fields or openings. The standard used for determining maximum field width was to look where the longest line could be drawn through a crop field, orchard, or opening. That line became the length.

Then the maximum width was measured along the longest perpendicular line crossing the length of the field, orchard, or opening.

Some of the MIRIS code terminology should be clarified with respect to which codes were included for forest, agriculture, and development land-use delineations for HSI calculations. Forested areas included all forested areas (400 codes), forested wetlands (611 and 612 codes), herbaceous openings (31 code), and shrub areas (32 code). Herbaceous openlands and shrub areas were considered as forest types in the fall and winter food sub-model because they contributed to both stem densities and woody browse. Permanent pasture, shrublands, and herbaceous openlands were classified as openings for spring food sub-model calculations.

Herbaceous openlands were counted as both forested area and as open area in the spring food HSI sub-model because herbaceous openlands contributed to both stem densities and herbaceous productivity during May through October. Most openings encountered around fields were comprised of scattered trees and clumps of regenerating woody species along with relatively open understories that provided herbaceous forage. Since stem density and herbaceous productivity were calculated as SI's in separate sub-models, herbaceous openings could be included in each of the SI calculations without being "double-counted". Urban areas (100 codes) were combined and considered as general development.

Some of the HSI variables were modified for the data that was collected and for programming workable equations into PC ARC/INFO. The stem density variable for fall and winter food included all woody stems $\geq$ 1.5 m, instead of woody stems $\geq$ 1.0 m with $\leq$ 6.30 cm dbh. Assigned site indices for red pine and northern white cedar were based on general soil types in the area surrounding crop fields and the MDNR's compartment map site index calculations for those 2 species. Alfalfa was given a SI of 0.40 in the fall and winter food HSI sub-model. The 0.40 SI for alfalfa is slightly higher than the SI assigned to hay because alfalfa is more nutritious than hay and it is persistent through early autumn (H. Campa, Mich. State Univ., Dept. Fisheries and Wildlife, pers. commun.).

Since the HSI model did not assign tart cherries an SI value, orchards were assigned a fall and winter food SI of 0.80 because they provided some browse year-round. Orchards were assigned a spring food SI of 1.0 because deer forage on cherry trees during the spring and summer (orchardists, pers. commun.).

Herbaceous productivity for the spring food HSI sub-model was calculated using mean horizontal cover percentages from the 0-0.5 m strata as the percent herbaceous ground cover and the 0-1.5 m strata as the percent shrub cover (the matrix used to calculate SI's for herbaceous productivity is labeled in the model as alternate

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M2V2 SI graph).

For the thermal cover sub-model, the distance to the nearest thermal cover stand was defined as the distance to the nearest thermal cover stand $\geq$ 2.0 ha. For this project, thermal cover was defined as lowland conifers and pine and upland conifers. The distance from crop field edges to the edge of the nearest thermal cover stand was calculated. The SI of the nearest stand representated the quality of thermal cover available to deer within or outside of each evaluation area. The shortest distance was used to evaluate thermal cover quality because it was more practical to calculate the nearest stand's SI than it would have been to calculate SI's for every conifer stand within 8.0 km of each crop field or orchard.

The equations in the HSI model were not flexible enough to account for land-use changes that might occur in the future or to make assessments about the relationships between croplands and different levels of deer habitat quality. All of the HSI model equations, except thermal cover, were modified so that the resulting HSI's made more biological sense for the purposes of this project. Changes that were made to equations are described in the following paragraphs. The modifications also possibly made the sub-models more practical deer habitat evaluation tools for the high and the low deer density study areas.

Agricultural polygons within coverages presented a problem in that they were not delineated by field, only by the total area in field crop, orchard, feed lot, or pasture categories. It was impractical to digitize each crop field within an evaluation area. Therefore, SI's for any fields or orchards that were used in this study, and fell into an evaluation area for another field, were assumed to represent the habitat suitability of all agricultural polygons. A weighted average was calculated using each field's or orchard's respective area as the weighting factor and each field's or orchard's calculated SI as the variable to be weighted. The weighted average was then used as the SI for the remaining agricultural area within each respective evaluation area. A minimum of 3 fields was used to calculate each weighted average. If an evaluation area did not have 3 fields that were used in this study, additional fields were selected and their widths, crop type, and management practices were input into the HSI database for that coverage. Weighted averages were used for agricultural SI calculations in the fall and winter food and in the spring food sub-models, as well as in the optional security cover equation that included agricultural fields as a form of security cover.

An optional equation was developed for the security cover sub-model. Agriculture was added as an option to the PC ARC/INFO HSI program so that the contribution of agricultural crops to deer security cover could be evaluated. By adding an agricultural option for subsequent HSI security cover calculations, security cover HSI's that include agriculture can be compared to the original HSI calculation (that does not include the agricultural component) and the contribution of agricultural crops to security cover can be determined.

Based on growth characteristics, corn, alfalfa, hay, and a catch-all category that included wheat, oats, and barley were assumed to provide security cover. All of the specified crop types can grow to a height that could provide potential cover for deer. The original white-tailed deer HSI model did not consider agricultural areas as potential security cover, nor is there much literature about security cover quality that crops might provide. Therefore, SI's were assigned based on information generated from the wooded vegetation data. Most security cover values were calculated by the PC ARC/INFO HSI program to be approximately 0.70 for wooded areas within evaluation areas. Corn was assigned an SI of 0.70 during its later growth stages (mid-July to harvest time) since its height and the proximity of stalks can provide security cover comparable to that of some wooded areas. Since second alfalfa crops grew later during the summer when corn crops were relatively tall, corn fields were assigned an SI of 0.70 for habitat quality evaluation during the time the second alfalfa crop grew. Early corn growth stages (early June-mid-July) received a value of 0.10 and this SI was used for habitat quality evaluation during the time first alfalfa crops grew.

Because corn provided minimal security cover early in the red kidney bean growing season and cover comparable to wooded areas later in the season, corn fields located within red kidney bean field evaluation areas were assigned SI's of 0.30. Alfalfa was assigned a SI of 0.30 since its height is lower than corn and wooded areas and because its density and height can be extremely variable. All grain crops also received SI's of 0.30 because their height was comparable to the height of alfalfa. Orchards were assigned values of 0.60, slightly less than the average wooded cover, because pruning and mowing results in less cover and no growth under trees or between rows.

Fields in each evaluation area that had known crop types and management practices (minimum of 3 fields per evaluation area) were used to calculate a weighted mean SI for security cover, with agricultural areas included, for the remaining agricultural areas. The fields with known crops and management practices were assigned security cover SI's associated with the different crop types that were mentioned above. The SI's for agricultural area as security cover were then added to the SI_{sc} equation. The total area in security cover types for the SI_{sc} calculation and the M3V3 variable then included both agricultural and forested areas.

An urban SI and an opening SI were 2 equations that were added to the fall and winter food portion of the PC ARC/INFO HSI program. Urban areas, or general development, and openings, such as pasture and fallow fields, were added to the fall and winter food sub-model because urban areas and openings have potential to contribute fall and winter food. Urban and open areas were assigned a SI of 0.01 and the total area in urban land-use and in openings was weighted by the total evaluation area and added into the SI_{FWF} equation. The area of openings and of urban land-use then became fall and winter food types for the final weighting variable, the percent of the total evaluation area that was in fall and winter food types (M1V9).

Adding urban and opening components to the fall and winter food sub-model had the benefit of providing an added weighting procedure. The percent of total evaluation area in fall and winter food types (M1V9), calculation did not adequately weight land-use types that were not in forested or agricultural classifications. Any land-use changes that were made to a coverage were not adequately weighted when the percent of the evaluation area in fall and winter food types remained equal to, or above, 60% (which receives a SI of 1.0). For example, when a large crop field was changed to development in one of the coverages the fall and winter food HSI value almost doubled. The crop field that was deleted had an SI of 0.0 so the HSI increased when the field was removed and its 0.0 contribution was alleviated. The HSI increased because there was still more than 60% of the evaluation area in fall and winter food types after the area of the field had changed to a land-use that contributed little to fall and winter food. This manipulation demonstrated that the weighting factor of percent of evaluation area in fall and winter foods did not compensate for other land-uses that marginally contributed to fall and winter food quality. Therefore, the open and urban SI's were added to the fall and winter food and spring food calculations make the respective sub-model's HSI's a better evaluation of habitat quality.

An urban SI was added to the spring food sub-model for the same reasons as for the fall and winter food sub-model. Urban areas were assigned an SI value of 0.01 and weighted by the area they contributed to the entire evaluation area. The SI's for both openings and agriculture were reworked so that the calculations weighted these areas in a more mathematically rational manner. The SI_{open} equation was changed so that M2V1 multiplied by M2V2 became the SI value for each opening (each open polygon). The individual open polygon SI was then weighted by multiplying its respective SI value by the quotient of its respective area divided by the total area in openings. This SI_{open} was then multiplied by the quotient of the total area divided by the total area in the evaluation area (M2V3). The same procedure was used for the SI_{ag} calculation (this makes 2 different M2V3 SI's, one for openings and one for agriculture).

DATA ANALYSIS

Paired t-tests (Sprinthall 1990) were applied, using Number Cruncher Statistical System (NCSS) version 4.21 (Hintze 1986), to test for biomass differences between exclosures and areas open to foraging for all 3 crop types. Paired samples were tested for significant differences per harvest, per field or orchard, and per edge category in alfalfa fields and red kidney bean fields during 1993 and 1994. One-tailed t-tests were used to test the hypothesis that crop growth was greater within exclosures than outside of exclosures. Because this was a field study that inherently had relatively high variability in data sets, significance levels were set at $P \leq 0.10$.

The Kruskal-Wallis one-way analysis of variance test (Sokal and Rohlf 1995) was used to determine if production differences associated with 1 of the adjacent edge categories were different from production differences in the other edge categories. Kruskal-Wallis tests were done using NCSS, 4.21 (Hintze 1986).

Predictive crop loss models were constructed with stepwise multiple regression analysis (Sokal and Rohlf 1995) using the Statistical Analysis System (SAS) version 6.1

(Statistical Analysis Systems Institute 1995). Production loss estimates were the dependent variables and field and landscape variables were the independent variables (Tables 5 and 6).

Plots were generated for dependent and independent variables to check for possible curvilinear relationships. In addition, each continuous variable was analyzed for its relationship with production levels of each harvest using Pearson's correlation coefficient (SAS, 6.1). Independent variables were retained for regression analyses if $P \leq 0.20$.

Variables that had categorical data were analyzed for significant relationships with production data using NCSS, 4.21 (Hintze 1986). Unpaired t-tests were used when a variable was comprised of 2 categories and one-way analysis of variance was used if a variable had more than 2 categories (Sprinthall 1990). Variables were retained for regression analyses if $P \leq 0.10$.

Variables that showed statistically significant Pearson's correlation coefficients indicated possible trends that affected levels of production loss. All statistically significant variables were then used in stepwise multiple regression procedures to determine which variables best described the greatest amount of variation and predicted levels of production loss. A significance level of $P \leq 0.15$ was set for entry into stepwise models. Residuals were plotted to test linearity assumptions. The best models were selected based on the following criteria: models significant at $P \leq 0.15$, all selected variables significant at $P \leq 0.15$, and the model's R^2 did not substantially increase with the addition of other variables.

RESULTS

Crop Loss Estimates

Because this thesis is providing information primarily to natural resource managers and to agricultural producers, crop production results are presented in 2 ways. Statistically significant results are presented to illustrate patterns of crop loss and to set confidence levels as to whether or not the production differences can be attributed to deer. Crop loss from deer was considered to be only those production differences that were statistically significant. In addition, mean production differences (between exclosures and open areas) are also presented so that agricultural producers can make their own decisions about which production loss levels constitute damage for them.

Within the text, production losses (kg/ha) are listed with the percent production loss they represented in parentheses. Production loss percentages were calculated by dividing the estimated weight loss (kg/ha) by the estimated weight (kg/ha) within exclosures.

Alfalfa Fields

Statistically significant production differences were found for the first and second alfalfa harvests during 1993 and 1994 (Table 7). The second alfalfa harvest during 1994 had the greatest statistically significant production loss ($P \leq 0.05$). The mean weight loss for all harvests during 1993 and 1994 combined was 84.78 kg/ha (5.23%). The average weight loss was 93.89 kg/ha (4.75%) for the first harvests during 1993 and 1994 combined and 75.67 kg/ha (5.72%) for the second harvests during 1993 and 1994 combined.

Production losses in individual fields during 1993's first harvest ranged from 0.0-307.80 kg/ha (0.0-21.94%), and from 0.0-312.10 kg/ha (0.0-11.90%) for the second harvest. During 1994, the first harvest had a 0.0-994.30 kg/ha (0.0-50.22%) range of production loss and the second harvest ranged from 0.0-355.60 kg/ha (0.0-31.32%).

All 3 edge categories were present around the majority of the alfalfa fields for each of the harvests (Table 8). The development edge category was adjacent to the fewest number of fields for each harvest (56.25-76.47% of fields were adjacent to development), while agriculture was adjacent to 85-94.12% of the fields and wooded areas were adjacent to 81.82-100%

Table 7. Mean alfalfa production in exclosures and in areas open to foraging (and standard errors), in kg/ha dry matter, for first and second harvests during 1993 and 1994 in northern lower Michigan.

Year and harvest	Exclosed (SE)	Open (SE)	Difference (SE)	% Loss
1993				
1st harvest	1394.53 (86.33)	1311.33 (92.41)	83.50[a] (52.03)	5.60
2nd harvest	1626.44 (132.11)	1562.39 (123.05)	64.04[a] (39.59)	2.91
1994				
1st harvest	2296.43 (153.56)	2192.16 (159.98)	104.28[a] (65.45)	3.89
2nd harvest	1440.72 (131.15)	1353.42 (144.14)	87.29[b] (32.73)	8.53

[a]Statistically significant production loss, $P \leq 0.10$ (paired t-test, Sprinthall 1990)
[b]Statistically significant production loss, $P \leq 0.05$ (paired t-test)

Table 8. Percent of alfalfa fields with each type of adjacent edge category for each harvest during 1993 and 1994 in northern lower Michigan.

Year and harvest	N	Core	Ag[a]	Wooded	Dev[b]
1993					
1st harvest	11	81.82	90.91	81.82	63.64
2nd harvest	16	87.50	93.75	87.50	56.25
1994					
1st harvest	20	60.00	85.00	100	65.00
2nd harvest	17	64.71	94.12	100	76.47

[a]Agriculture
[b]Development

of the fields. Sixty to 87.50% of the fields had core areas.

Wooded edges were adjacent to the highest percentage of alfalfa field perimeters (Appendix E). The agriculture category had the next highest percentage of edge along fields. The development category had the least edge length adjacent to alfalfa fields. The average perimeter length around alfalfa fields was 1330 m.

Statistically significant production differences were found in a mix of the different edge categories when paired t-tests were calculated with data from the core area and from each edge category. No statistically significant differences ($P > 1.0$) were detected when mean production differences associated with the 3 edge categories and the core area were compared with each other.

There were no statistically significant production differences ($P > 0.10$) in the core areas for any of the harvests (Table 9). The average weight loss in core areas for all harvests combined (1993 and 1994) was 35.78 kg/ha (3.74%). The combined first harvests (1993 and 1994) had no loss. The combined second harvests (1993 and 1994) had an average weight loss of 87.36 kg/ha (4.86%).

The range of production loss in core areas for individual fields during 1993 was 0.0-490.60 kg/ha (0.0-59.82%) for the first harvest and 0.0-936.30 kg/ha (0.0-41.49%) for the second harvest. During 1994's first harvest, production loss in individual fields ranged from 0.0-1493.10 kg/ha (0.0-56.42%) and from 0.0-451.80 kg/ha (0.0-67.51%) for the second 1994 harvest.

Statistically significant production differences ($P \leq 0.01$) were associated with agricultural edges for the second harvest during 1993 and for the second harvest ($P \leq 0.05$) during 1994 (Table 10). For all harvests combined (1993 and 1994), the average weight loss was 60.66 kg/ha (3.84%). The combined first harvests (1993 and 1994) had no loss and the combined second harvests (1993 and 1994) had an average weight loss of 126.56 kg/ha (6.73%).

Production losses in areas of individual fields that were adjacent to agriculture edges had a 0.0-487.70 kg/ha (0.0-24.82%) range of production loss during 1993's first harvest. Losses in fields during 1993's second harvest ranged from 0.0-670.90 kg/ha (0.0-30.13%). Fields in

Table 9. Mean alfalfa production in exclosures and in areas open to foraging in core areas (and standard errors), in kg/ha dry matter, for first and second harvests during 1993 and 1994 in northern lower Michigan.

Year and harvest	Exclosed (SE)	Open (SE)	Difference (SE)	% Loss
1993				
1st harvest	1237.64 (137.04)	1403.49 (197.24)	165.84 (116.15)	0.00
2nd harvest	1611.43 (159.46)	1546.71 (141.03)	64.71 (92.19)	1.22
1994				
1st harvest	2632.23 (169.96)	2498.00 (233.07)	134.23 (146.12)	5.22
2nd harvest	1614.05 (203.98)	1549.55 (231.98)	110.00 (87.01)	8.50

Table 10. Mean alfalfa production in exclosures and in areas open to foraging along agricultural edges (and standard errors), in kg/ha dry matter, for first and second harvests during 1993 and 1994 in northern lower Michigan.

Year and harvest	Exclosed (SE)	Open (SE)	Difference (SE)	% Loss
1993				
1st harvest	1421.79 (118.05)	1369.01 (71.11)	52.78 (98.8)	1.90
2nd harvest	1564.01 (163.24)	1432.11 (148.75)	131.91[b] (52.04)	6.42
1994				
1st harvest	2272.81 (211.02)	2336.07 (186.89)	63.26 (95.91)	0.00
2nd harvest	1572.28 (152.91)	1451.08 (153.68)	121.21[a] (68.45)	7.03

[a]Statistically significant production loss, $P \leq 0.05$ (paired t-test, Sprinthall 1990)
[b]Statistically significant production loss, $P \leq 0.01$ (paired t-test)

the first harvest of 1994 had production losses ranging from 0.0-623.30 kg/ha (0.0-18.88%) and fields in the second harvest ranged from 0.0-747.60 kg/ha (0.0-31.32%).

Areas of alfalfa fields that were adjacent to wooded edges showed statistically significant production differences for 1994's first harvest ($P \leq 0.10$) and second ($P \leq 0.025$) harvest (Table 11). The average weight loss for all harvests combined was 113.23 kg/ha (5.83%). First harvests combined (1993 and 1994) had a 187.06 kg/ha (8.52%) mean crop loss and second harvests combined averaged 39.40 kg/ha (3.14%) production loss.

For areas along wooded edges in individual fields, there was a range of production loss between 0.0-1418.50 kg/ha (0.0-51.49%) for fields in 1993's first harvest. For fields in the second 1993 harvest, production loss ranged from 0.0-244.90 kg/ha (0.0-16.56%). Production losses in the fields for the first harvest during 1994 ranged from 0.0-869.60 kg/ha (0.0-47.95%). Fields in the second 1994 harvest had 0.0-419.80 kg/ha (0.0-41.99%) range of production loss.

Production losses associated with development edges were significant for the first harvest during 1993 ($P \leq 0.05$) and for the second harvest during 1994 ($P \leq 0.10$) (Table 12). The mean production loss for all harvests combined was 119.89 kg/ha (8.03%). The average weight loss for the combined first harvests (1993 and 1994) was 94.86 kg/ha (9.86%) and for the combined second harvests

Table 11. Mean alfalfa production in exclosures and in areas open to foraging along wooded edges (and standard errors), in kg/ha dry matter, for first and second harvests during 1993 and 1994 in northern lower Michigan.

Year and harvest	Exclosed (SE)	Open (SE)	Difference (SE)	% Loss
1993				
1st harvest	1494.07 (169.96)	1279.03 (94.67)	215.03 (153.86)	10.00
2nd harvest	1722.62 (159.47)	1762.27 (150.43)	39.65 (95.78)	0.00
1994				
1st harvest	2283.51 (155.72)	2124.43 (170.29)	159.08[a] (91.40)	7.03
2nd harvest	1347.26 (114.38)	1275.27 (134.99)	118.45[b] (70.34)	6.28

[a]Statistically significant production loss, $P \leq 0.10$ (paired t-test, Sprinthall 1990)
[b]Statistically significant production loss, $P \leq 0.025$ (paired t-test)

Table 12. Mean alfalfa production in exclosures and in areas open to foraging along development edges (and standard errors), in kg/ha dry matter, for first and second harvests during 1993 and 1994 in northern lower Michigan.

Year and harvest	Exclosed (SE)	Open (SE)	Difference (SE)	% Loss
1993				
1st harvest	1389.17 (236.93)	1140.12 (230.47)	249.05[b] (110.54)	19.72
2nd harvest	1813.26 (193.31)	1635.64 (173.77)	177.63 (124.25)	6.53
1994				
1st harvest	2263.71 (230.39)	2204.38 (220.31)	59.33 (137.97)	0.00
2nd harvest	1412.19 (164.28)	1299.98 (171.18)	112.21[a] (70.53)	5.86

[a]Statistically significant production loss, $P \leq 0.10$ (paired t-test, Sprinthall 1990)
[b]Statistically significant production loss, $P \leq 0.05$ (paired t-test)

mean crop loss was 144.92 kg/ha (6.20%).

Production losses along development edges in individual fields ranged from 0.0-746.00 kg/ha (0.0-36.40%) during 1993's first harvest and from 0.0-813.80 kg/ha (0.0-40.61%) during 1993's second harvest. Production losses in fields during the first harvest in 1994 ranged from 0.0 kg/ha to 1163.20 kg/ha (0.0-33.21%) and from 0.0-500.20 kg/ha (0.0-30.96%) for the second harvest.

Only 2 landowners kept records of their alfalfa yields. The moisture content of the 2 yields for which information was available was 60.0-62.0%, making a comparison between the yields and the dry weights of paired samples not standardized. The lack of yield information made it impossible to relate estimated production losses to actual yields and calculate an estimate of pounds or tons lost per acre or per field based on reported yields.

Red Kidney Bean Fields

Red kidney bean fields located within the high deer density study area had statistically significant production losses during the 1993 harvest ($P \leq 0.01$) and the 1994 harvest ($P \leq 0.0005$) (Table 13). Fields in the low deer density study area did not show statistically significant production differences during either year ($P > 0.10$). The average production loss was 205.63 kg/ha (9.87%) in the high

Table 13. Mean red kidney bean production in exclosures and in areas open to foraging (and standard errors), in kg/ha, in the high and the low deer density areas during 1993 and 1994 in northern lower Michigan.

Year and deer density	Exclosed (SE)	Open (SE)	Difference (SE)	% Loss
1993				
High density	1750.39 (115.59)	1565.25 (123.44)	185.14[a] (97.25)	10.78
Low density	3860.21 (455.43)	3773.49 (451.23)	86.73 (127.60)	2.09
1994				
High density	2358.64 (266.90)	2132.53 (240.71)	226.11[b] (51.33)	8.96
Low density	3381.77 (516.44)	3231.43 (357.74)	150.34 (169.42)	1.70

[a]Statistically significant production loss, $P \leq 0.01$ (paired t-test, Sprinthall 1990)
[b]Statistically significant production loss, $P \leq 0.0005$ (paired t-test)

deer density area when 1993 and 1994 harvest data were combined. In the low deer density area, the average production loss was 118.54 kg/ha (1.7%) when the 1993 and 1994 harvests were combined.

Individual fields in high density areas had production losses ranging between 0.0-542.00 kg/ha (0.0-31.80%) during 1993 and between 0.0-496.10 kg/ha (0.0-20.29%) during 1994. In the low deer density areas, crop losses in individual fields ranged from 0.0-643.90 (0.0-15.62%) during 1993 and from 0.0-704.4 kg/ha (0.0-13.86%) during 1994.

Overall, the development edge category was adjacent to the fewest number of red kidney bean fields (Table 14). Other agricultural fields were adjacent to 50-90% of the bean fields and wooded areas were adjacent to 80-100% of the bean fields. At least 70% of the red kidney bean fields had core areas.

For both deer density areas, the greatest percentage of red kidney bean field perimeter length was adjacent to wooded edges (Appendix E). Agriculture edges had the next highest percentage and development edges bordered the least amount of red kidney bean field edge. Field perimeter length averaged 1669 m in the high deer density area and 2075 m in the low deer density areas.

When paired t-tests were applied to red kidney bean samples, significant production losses were detected along fewer edge categories than in alfalfa fields. Kruskal-Wallis analyses did not show any statistically

Table 14. Percent of red kidney bean fields with each type of adjacent edge category for each harvest in the high and the low deer density areas during 1993 and 1994 in northern lower Michigan.

Year and deer density	N	Core	Ag[a]	Wooded	Dev[b]
1993					
High density	10	70.00	80.00	100	50.00
Low density	8	75.00	50.00	87.50	75.00
1994					
High density	10	80.00	90.00	80.00	60.00
Low density	7	85.71	85.71	100	57.14

[a]Agriculture
[b]Development

significant differences among the mean production differences for the 3 edge categories and the core area.

No significant production losses ($P > 0.10$) were detected for core areas in either the high or the low deer density study areas in either year (Table 15). Mean production loss for both years combined in the high deer density area was 110.63 kg/ha (4.31%). There was no detectable production loss ($P > 1.0$) in the low deer density area when both years were combined.

During 1993, individual red kidney bean fields in the high deer density area had production losses in core areas ranging from 0.0-807.00 kg/ha (0.0-27.63%) and from 0.0-769.10 kg/ha (0.0-37.64%) during 1994. Fields in the low deer density area had production loss in individual fields ranging from 0.0-8.12 kg/ha (0.0-0.16%) during 1993

Table 15. Mean red kidney bean production in exclosures and in areas open to foraging in core areas (and standard errors), in kg/ha, in the high and the low deer density areas during 1993 and 1994 in northern lower Michigan.

Year and deer density	Exclosed (SE)	Open (SE)	Difference (SE)	% Loss
1993				
High density	2070.24 (187.03)	2050.23 (159.76)	20.01 (218.92)	3.11
Low density	3574.73 (451.89)	4042.80 (505.41)	468.07 (236.54)	0.00
1994				
High density	2459.86 (333.13)	2258.63 (275.14)	201.24 (137.96)	5.50
Low density	4028.14 (575.46)	3822.92 (405.78)	205.22 (198.31)	1.18

and from 0.0-742.30 kg/ha (0.0-12.84%) during 1994.

There were also no significant ($P > 0.10$) differences in red kidney bean production along agriculture edges for either deer density area during either year (Table 16). The average production loss for areas bordering other agricultural fields was 89.19 kg/ha (5.36%) when 1993 and 1994 harvest data were combined for the high deer density area. There were no losses in the low deer density area.

Percent production loss for areas in individual fields that were adjacent to other agricultural fields ranged from 0.0-686.80 kg/ha (0.0-43.87%) in the high deer density area during 1993 and from 0.0-539.71 kg/ha (0.0-36.65) during 1994. Individual fields in the low deer density area had crop losses ranging from 0.0-1042.40 kg/ha (0.0-17.92%) during 1993 and from 0.0-708.1 kg/ha (0.0-15.17%) during 1994.

Most of the significant losses found in the red kidney bean fields were detected along wooded edges. Both the high and the low deer density areas showed significant production loss at similar intensities along this edge category (Table 17). The high deer density area had an average production loss of 282.51 kg/ha (13.02%) during 1993 and 1994 combined. In the low deer density area, the average weight loss during 1993 and 1994 was 337.15 kg/ha (7.94%).

Areas adjacent to wooded cover in individual red kidney bean fields in the high deer density area had crop losses that ranged from 0.0-1167.70 kg/ha (0.0-52.77%) during 1993

Table 16. Mean red kidney bean production in exclosures and in areas open to foraging along agricultural edges (and standard errors), in kg/ha, in the high and the low deer density areas during 1993 and 1994 in northern lower Michigan.

Year and deer density	Exclosed (SE)	Open (SE)	Difference (SE)	% Loss
1993				
High density	1759.00 (132.58)	1701.45 (195.14)	57.55 (113.80)	3.97
Low density	3834.48 (577.17)	3902.60 (345.45)	68.13 (421.99)	0.00
1994				
High density	2213.87 (277.20)	2093.03 (316.97)	120.83 (94.10)	6.74
Low density	2970.05 (431.06)	3103.87 (85.21)	133.82 (208.72)	0.00

Table 17. Mean red kidney bean production in exclosures and in areas open to foraging along wooded edges (and standard errors), in kg/ha, in the high and the low deer density areas during 1993 and 1994 in northern lower Michigan.

Year and deer density	Exclosed (SE)	Open (SE)	Difference (SE)	% Loss
1993				
High density	1519.17 (154.18)	1233.28 (123.55)	285.89[b] (116.24)	16.12
Low density	3800.87 (508.63)	3541.07 (521.51)	259.80[a] (122.72)	7.25
1994				
High density	2318.99 (371.80)	2039.86 (365.34)	279.12[c] (67.40)	9.91
Low density	3334.33 (561.21)	2919.84 (414.10)	414.49[b] (169.29)	8.62

[a]Statistically significant production loss, $P \leq 0.05$ (paired t-test, Sprinthall 1990)
[b]Statistically significant production loss, $P \leq 0.025$ (paired t-test)
[c]Statistically significant production loss, $P \leq 0.005$ (paired t-test)

and from 0.0-451.80 kg/ha (0.0-30.38%) during 1994. Fields in the low deer density area had percent losses along wooded edges ranging from 0.0-33.71% during 1993 and from 0.0-23.35% during 1994.

Along development edges, red kidney bean production losses averaged 236.9 kg/ha (12.19%) in the high deer density area when 1993 and 1994 harvests were combined (Table 18). In the low deer density area, the mean production loss for both years combined was 77.09 kg/ha (1.12%).

Production losses along development edges in individual red kidney bean fields ranged from 0.0-554.80 kg/ha (0.0-36.38%) during 1993 and from 0.0-1000.00 kg/ha (0.0-20.77%) during 1994 in the high deer density area. In the low deer density area, production losses in individual fields ranged from 0.0-784.93 kg/ha (0.0-25.64%) during 1993 and from 0.0-555.50 kg/ha (0.0-10.9%) during 1994.

Estimated red kidney bean yields in the high and the low deer density study areas were greater than those reported by the farmers (farmers, pers. commun. during bean harvest or from the telephone survey, Appendix D). Individual field estimates in this study ranged approximately 8% to 80% greater than farmers' estimates. Discrepancies between estimated production levels and yields reported by farmers might have resulted from the sampling scheme used (11.0 m^2 out of an entire field) and from farmers' estimates being an estimate of average yield per

Table 18. Mean red kidney bean production in exclosures and in areas open to foraging along development edges (and standard errors), in kg/ha, in the high and the low deer density areas during 1993 and 1994 in northern lower Michigan.

Year and deer density	Exclosed (SE)	Open (SE)	Difference (SE)	% Loss
1993				
High density	1738.26 (269.67)	1600.36 (325.22)	137.90 (120.58)	12.11
Low density	3804.12 (689.60)	3831.25 (688.64)	27.13 (213.37)	0.00
1994				
High density	2636.48 (562.13)	2300.58 (444.41)	335.90[a] (163.88)	12.27
Low density	4023.40 (593.86)	3842.10 (452.18)	181.30 (205.97)	2.23

[a]statistically significant production loss, $P \leq 0.10$ (paired t-test, Sprinthall 1990)

acre for their entire fields, not for the entire field. As with alfalfa, there can be no accurate estimate of pounds or bags lost per acre or per field relative to reported yields.

Tart Cherry Orchards

Information about the amount of deer browsing on tart cherry trees was collected from 1,100 trees during 1993 and 1994 (900 trees were used for browsed CAG twig calculations and branches from 200 trees were used for counting the number of buds that produced cherries). Only 2 orchards produced useable data for comparing the number of buds that produced cherries in fenced areas and in areas open to browsing because 2 of the 4 orchards had winter kill in the fenced areas.

Effects of winter kill on cherry production were apparent by June when trees in the 2 areas had little to no flowering. This made comparisons between deer browsing on buds and cherry production impossible in those orchards. Of the 2 orchards in which data were collected, 1 orchard had a 1.13% mean production loss, while the second orchard had 8.65% greater production in the area open to browsing (Table 19). Neither of the orchards had statistically significant cherry production loss ($P > 0.10$) when cherry production was calculated from the number of browsed buds divided by the number of cherries produced on selected tree

Table 19. Mean percentages (and standard errors) of tart cherry production on randomly selected branches during 1994 in areas open to browsing and in fenced areas of orchards in northern lower Michigan.

	Orchard Number			
Area	1 (SE)	2	3	4 (SE)
Open	23.81 (2.59)	NS	NS	17.54 (2.82)
Fenced	24.94 (2.75)	winter kill	winter kill	8.89 (2.16)
Difference	-1.13			8.65

NS Not sampled

branches (Table 19). The average percentage of browsed CAG twigs during 1993 was 14.76 (SE=7.4) and 7.66 (SE=6.9) during 1994 (Table 20). The average was 10.82% (SE=7.96) for 1993 and 1994 combined.

The greatest percentage of browsed CAG twigs was 19.46 and the least was 0.29. Orchard number 1 had a relatively low percentage of browsing on CAG twigs during 1993 and 1994. Browse percentages in orchard number 2 remained relatively high during both years. There was a 9.32% and a 10.69% decrease, respectively, for orchards 3 and 4. Orchard number 5 was sampled only in 1994 and had the least amount of browsing.

Table 20. Mean percentages (and standard errors) of browsed current annual growth twigs during 1993 and 1994 in areas open to browsing in tart cherry orchards in northern lower Michigan.

	Orchard Number				
Year	1 (SE)	2 (SE)	3 (SE)	4 (SE)	5 (SE)
1993	1.94 (0.46)	18.86 (1.83)	18.77 (0.92)	19.46 (2.18)	NS
1994	0.69 (0.24)	19.11 (1.68)	9.45 (0.80)	8.77 (1.60)	0.29 (0.15)

[NS]Not sampled

Deer browsing on tart cherry trees can impact young tree growth and delay the time at which trees reach production age (J. Nugent, Northwest Horticultural Research Station, pers. commun.). An example of the costs associated with establishing a tart cherry orchard is provided by Kelsey et al. (1989) (Appendix A). Deer browsing could potentially impact these costs by delaying the time at which profits are returned from trees that were delayed in reaching production age (usually 5 years).

Crop Damage Control Methods

Four of the 5 tart cherry orchardists used high tensile electric fencing to protect selected orchard blocks. All 5 orchardists used soap, tankage, or a combination of the 2 on some of their trees to deter deer browsing in areas that were open to deer browsing. None of the other landowners used any physical barriers or repellents to protect their crops. Summer shooting permits and block permits were the predominant forms of crop damage control.

The reported percentages of used permits pertain to only those landowners who were involved in this study. The percentages reflect summer shooting permit and block permit information that landowners returned to the MDNR. The percentages of landowners who received summer permits or block permits during this study might not be an indication of percentages of all farmers who do, or do not, receive permits throughout Michigan. Block permit information is presented for the year prior to data collection for each field or orchard.

During 1993, 1 out of the 13 alfalfa growers received summer shooting permits and 6 of the 10 issued permits were used. During 1994, 4 out of the 18 alfalfa growers were issued summer shooting permits and 11 of the 30 issued permits were used.

Four of the 8 red kidney bean growers in the high deer density area were issued summer shooting permits during 1993 and 11 of the 70 issued permits were used. During 1994, 4 of the 6 red kidney bean growers were issued summer shooting permits and 9 of the 18 issued permits were used.

In the low deer density area, 1 of the 3 red kidney bean growers received 5 summer shooting permits and none were used during 1993. No summer shooting permits were used by the 1 red kidney bean grower during 1994. One of the 4 orchardists received 5 summer shooting permits during 1993 and none were used. During 1994, 1 of the 5 orchardists received 5 summer shooting permits and none were used.

During 1992, 8 of the 13 alfalfa growers (growers who participated in the study during 1993) received block permits and 125 of the 185 issued permits were used. During 1993, 7 of the 18 alfalfa growers (growers who participated in the study during 1994) were issued block permits and 106 of the 185 issued permits were used.

During 1992, the MDNR issued block permits to 3 of the 8 red kidney bean growers in the high deer density area and 44 of the 90 issued permits were used. During 1993, 2 of the 6 farmers in the high density area received permits and 28 of the 45 issues permits were used.

None of the 3 red kidney bean growers in the low deer density area were issued block permits during either 1992 or 1993. Two of the 4 orchardists were issued block permits during 1992 and 19 of the 20 issued permits were used. During 1993, 2 of the 5 orchardists received block permits and 17 of the 30 issued permits were used.

There were no statistically significant (unpaired t-test, $P > 0.10$) differences for either production or browse percentages between those fields or orchards for which block or summer permits were issued and those fields or orchards for which no block or summer permits were issued. No attempt was made to evaluate if neighboring landowners used either type of shooting permit. Because all orchardists used some type of repellent, it was impossible to test for differences in browsed CAG twig percentages between those orchards that used tankage or soap with those that did not.

Habitat Quality Evaluation

The HSI was programmed into PC ARC/INFO and generated HSI sub-model values for evaluation areas around each field or orchard. Mean thermal cover values were consistently 0.0 for all crop types (Table 21). Thermal cover sub-model HSI's were disregarded because the thermal cover HSI equation was not weighted and this made the HSI impractical to use for this project. Only the distances to the nearest thermal cover stands from fields were used for analyses with crop production.

In addition to no variable weighting in the equation, vegetation sampling was not done in a way that adequately

Table 21. Mean white-tailed deer sub-model habitat suitability indices (HSI) for evaluation areas surrounding alfalfa fields, red kidney bean fields, and tart cherry orchards during 1993 and 1994 in northern lower Michigan.

	HSI fall/winter food (SE)	HSI spring food (SE)	HSI security cover (SE)	HSI thermal cover (SE)
Alfalfa				
1st harvest 1993	0.29 (0.02)	0.70 (0.06)	0.72 (0.00)	0.0 (0.0)
2nd harvest 1993	0.30 (0.02)	0.77 (0.07)	0.73 (0.04)	0.0 (0.0)
1st harvest 1994	0.25 (0.02)	0.73 (0.05)	0.68 (0.03)	0.0 (0.0)
2nd harvest 1994	0.25 (0.02)	0.72 (0.05)	0.65 (0.03)	0.0 (0.0)
Overall mean	0.27 (0.02)	0.73 (0.03)	0.70 (0.03)	0.0 (0.0)
Red kidney beans				
High density 1993	0.27 (0.00)	0.44 (0.05)	0.63 (0.07)	0.0 (0.0)
High density 1994	0.17 (0.03)	0.27 (0.05)	0.63 (0.07)	0.0 (0.0)
Overall mean	0.22 (0.05)	0.36 (0.09)	0.63 (0.07)	0.0 (0.0)
Low density 1993	0.27 (0.05)	0.41 (0.05)	0.73 (0.01)	0.0 (0.0)
Low density 1994	0.28 (0.06)	0.31 (0.04)	0.51 (0.07)	0.0 (0.0)
Overall mean	0.27 (0.01)	0.36 (0.05)	0.61 (0.10)	0.0 (0.0)
Tart cherry orchards				
1993	0.27 (0.03)	0.69 (0.12)	0.74 (0.01)	0.0 (0.0)
1994	0.27 (0.03)	0.68 (0.11)	0.74 (0.01)	0.0 (0.0)
Overall mean	0.27 (0.03)	0.69 (0.01)	0.74 (0.01)	0.0 (0.0)

assessed thermal cover stand characteristics. There were too many time constraints to sample the nearest thermal cover stand for each field or orchard. Thermal cover stands, determined by the HSI program run through PC ARC/INFO, were characterized by any conifers that were encountered in the 5 transects that were established around each field or orchard. This led to conifer basal areas that were too low to receive an SI's above 0.0. Also, if cedar was not encountered along any of the transects, the final thermal cover HSI became 0.0. More detail about why HSI's for thermal cover were not used in model analyses are stated in the discussion.

Evaluation areas around alfalfa fields and tart cherry orchards had similar mean fall and winter food HSI's and red kidney bean fields had a 0.02 lower mean value than those 2 crops (Table 21). Areas around alfalfa fields had the greatest HSI for spring food, followed by areas around tart cherry orchards. Areas surrounding red kidney bean fields in both of the deer density areas had the lowest spring food values with mean values approximately twice as low as the mean values for both alfalfa fields and tart cherry orchards. Security cover values had a 0.11 range between the highest and lowest mean HSI's. Areas around tart cherry orchards provided the highest quality security cover, followed by alfalfa fields and red kidney bean fields, respectively (Table 21).

Evaluation areas around tart cherry orchards had the greatest mean value for SI's for agriculture during fall and winter (Table 22). Evaluation areas around alfalfa fields had the second highest SI's for agriculture during the fall and winter, while areas around red kidney bean fields in both of the deer density areas had the lowest mean values. Evaluation areas around alfalfa fields and tart cherry orchards had greater mean SI's for agriculture during the spring than red kidney bean fields in both deer density areas had. Suitability indices for openings were greatest in evaluation areas around red kidney bean fields in the low deer density area, while red kidney bean fields in the high deer density area had the lowest mean SI for openings (Table 22). Mean SI's for forested areas were lowest in evaluation areas around tart cherry orchards and greatest in areas surrounding red kidney bean fields in the low deer density area.

Fall and winter food SI's for agriculture were higher than spring food SI's for agriculture (Table 22). This should not be viewed as agriculture providing higher quality food during fall and winter than during spring. The equations for calculating SI's for agricultural areas at different times of the year were different and this accounted for the difference in relative SI value scales. These SI's should be compared among crop types, not compared between each other.

When security cover values for agricultural areas were added into the security cover equation, overall HSI's

Table 22. Mean suitability indices (SI) for evaluation areas surrounding alfalfa fields, red kidney bean fields, and tart cherry orchards during 1993 and 1994 in northern lower Michigan.

	SI forest (SE)	SI ag[a] (SE)	SIag2[b] (SE)	SI open (SE)
Alfalfa				
1st harvest 1993	0.38 (0.02)	2.21 (0.40)	0.48 (0.06)	0.19 (0.02)
2nd harvest 1993	0.37 (0.02)	2.41 (0.54)	0.53 (0.06)	0.20 (0.03)
1st harvest 1994	0.27 (0.03)	2.59 (0.27)	0.53 (0.05)	0.19 (0.20)
2nd harvest 1994	0.29 (0.04)	2.61 (0.31)	0.51 (0.05)	0.20 (0.03)
Overall mean	0.33 (0.05)	2.46 (0.16)	0.51 (0.02)	0.20 (0.01)
Red kidney beans				
High density 1993	0.39 (0.01)	0.99 (0.21)	0.17 (0.04)	0.22 (0.03)
High density 1994	0.24 (0.04)	0.93 (0.29)	0.14 (0.03)	0.09 (0.02)
Overall mean	0.32 (0.08)	0.96 (0.03)	0.16 (0.02)	0.16 (0.07)
Low density 1993	0.35 (0.06)	2.62 (0.91)	0.12 (0.04)	0.28 (0.01)
Low density 1994	0.40 (0.08)	0.42 (0.08)	0.06 (0.02)	0.22 (0.02)
Overall mean	0.38 (0.03)	1.52 (1.10)	0.09 (0.03)	0.25 (0.03)
Tart cherry				
1993	0.27 (0.04)	8.21 (0.75)	0.50 (0.12)	0.18 (0.01)
1994	0.28 (0.05)	8.35 (0.50)	0.48 (0.11)	0.20 (0.01)
Overall mean	0.28 (0.01)	8.28 (0.07)	0.49 (0.01)	0.19 (0.01)

[a] SI for agriculture in fall and winter food sub-model
[b] SI for agriculture in spring food sub-model

decreased. Average security cover HSI's decreased from 0.70 to 0.54 (SE=0.02) around alfalfa fields, from 0.63 to 0.46 (SE=0.02) around red kidney bean fields in the high deer density areas, from 0.62 to 0.47 (SE=0.08) for bean fields in the low deer density area, and from 0.74 to 0.70 (SE=0.02) around tart cherry orchards. When values for croplands were included in security cover evaluations, orchards provided the highest quality security cover, followed by alfalfa fields and then red kidney bean fields.

A portion of the differences among the fall and winter food and spring food HSI's for alfalfa fields, red kidney bean fields, and tart cherry orchards are attributable to evaluation area construction. Since weighted averages were calculated with a minimum of 3 fields in each evaluation area, and since evaluation areas were centered around each field or orchard, the field or orchard for which a particular evaluation area was created greatly impacted SI equations. For example, mean SI's for agriculture during the spring followed the values that were given to each of the 3 crop types. Tart cherries had the highest individual crop value for spring food followed by alfalfa and then red kidney beans. Therefore, some of the means could be somewhat skewed from the values assigned to each crop type.

Landscape Characteristics and Vegetation Attributes

Average percentages of overall horizontal cover around all 3 crop types ranged from 42.0% to 56.0% (Table 23). Vertical cover also had a relatively small range (55.0-62.0%) among the evaluation areas around the 3 crop types (Table 23). The greatest overall mean stem densities per hectare were around tart cherry orchards. Areas around alfalfa fields had the second greatest mean number of stems per hectare. Red kidney bean fields in both deer density areas had the lowest overall mean stems per hectare. Overall means for stem density per hectare followed the same descending order of greatest to lowest values as security cover HSI's did. Overall mean basal areas ranged from 29.69 m^2/ha around red kidney bean fields in the low deer density area to 36.02 m^2/ha around red kidney bean fields in the high deer density area (Table 23).

Evaluation areas around alfalfa fields had the greatest overall mean number of hectares (427.69 ha) of agricultural land and tart cherry orchard evaluation areas had the lowest overall mean number of hectares (242.05 ha) of agricultural land (Table 24). Evaluation areas around red kidney bean fields in the low deer density area had 65.24 fewer overall mean hectares of agricultural land than bean fields in the high deer density area had.

The overall average number of wooded hectares was

Table 23. Mean vegetation characteristic values for evaluation areas surrounding alfalfa fields, red kidney bean fields, and tart cherry orchards during 1993 and 1994 in northern lower Michigan.

	HC[a] (SE)	VC[b] (SE)	BA[c] (SE)	SD[d] (SE)
Alfalfa				
1st harvest 1993	55.00 (4.99)	57.00 (2.80)	39.00 (7.72)	43232 (7890)
2nd harvest 1993	55.00 (4.48)	58.00 (2.55)	36.00 (7.21)	37156 (7557)
1st harvest 1994	39.00 (1.92)	53.00 (1.68)	36.00 (4.30)	31403 (5037)
2nd harvest 1994	39.00 (1.97)	53.00 (1.89)	31.00 (4.73)	29615 (5431)
Overall mean	47.00 (8.00)	55.00 (2.28)	36.00 (2.87)	35352 (5335)
Red kidney beans				
High density 1993	59.00 (2.30)	62.00 (2.53)	35.00 (6.48)	26885 (5244)
High density 1994	51.00 (5.99)	57.00 (1.80)	37.00 (7.49)	29630 (6719)
Overall mean	56.00 (3.50)	60.00 (2.50)	36.00 (0.50)	28615 (1730)
Low density 1993	42.00 (5.27)	58.00 (2.92)	36.00 (6.20)	23519 (3459)
Low density 1994	42.00 (4.71)	55.00 (3.31)	24.00 (4.30)	24721 (10257)
Overall mean	42.00 (0.00)	57.00 (1.50)	30.00 (6.00)	24120 (601)
Tart cherry				
1993	46.00 (3.68)	62.00 (1.77)	33.00 (5.81)	20900 (4397)
1994	43.00 (5.20)	62.00 (2.71)	39.00 (5.49)	65990 (41078)
Overall mean	45.00 (1.50)	62.00 (0.00)	36.00 (3.00)	0.19 (0.01)

[a] mean percent horizontal cover
[b] mean percent vertical cover
[c] mean basal area (m^2/ha)
[d] mean stem density (per ha)

Table 24. Mean hectares of different vegetation types in evaluation areas surrounding alfalfa fields, red kidney bean fields, and tart cherry orchards during 1993 and 1994.

	AG[a] (SE)	WD[b] (SE)	OP[c] (SE)	UH[d] (SE)
Alfalfa				
1st harvest 1993	428.18 (23.08)	670.00 (21.28)	81.64 (14.82)	89.82 (25.00)
2nd harvest 1993	439.75 (22.69)	663.94 (21.48)	103.00 (23.99)	81.88 (21.62)
1st harvest 1994	413.00 (23.89)	691.85 (23.21)	76.95 (14.90)	129.25 (22.65)
2nd harvest 1994	429.82 (17.70)	676.94 (18.77)	83.94 (16.92)	115.47 (24.48)
Overall mean	427.69 (9.57)	675.68 (10.41)	86.38 (9.92)	104.11 (19.10)
Red kidney beans				
High density 1993	431.10 (40.34)	682.00 (40.74)	80.00 (17.89)	84.50 (19.86)
High density 1994	380.70 (23.41)	726.30 (26.17)	36.80 (3.94)	124.40 (15.51)
Overall mean	405.90 (25.20)	704.15 (22.15)	58.40 (21.60)	104.45 (19.95)
Low density 1993	352.88 (41.77)	708.50 (39.80)	162.50 (20.16)	269.00 (34.18)
Low density 1994	328.43 (56.60)	781.43 (55.70)	201.00 (13.11)	285.71 (36.55)
Overall mean	340.66 (12.23)	744.97 (36.47)	181.75 (19.25)	277.36 (8.36)
Tart cherry				
1993	227.50 (30.30)	683.25 (77.25)	133.25 (34.74)	395.50 (36.63)
1994	256.60 (69.76)	726.60 (56.82)	140.20 (29.35)	348.20 (59.41)
Overall mean	242.05 (14.55)	704.93 (21.68)	136.73 (3.48)	371.85 (23.65)

Table 24 (cont'd).

	LH[e] (SE)	A/B[f] (SE)	P/UC[g] (SE)	LC[h] (SE)
Alfalfa				
1st harvest 1993	118.00 (23.90)	205.82 (24.25)	9.91 (3.33)	124.18 (18.38)
2nd harvest 1993	128.94 (25.59)	200.25 (27.62)	10.19 (3.18)	108.38 (17.45)
1st harvest 1994	132.15 (20.49)	182.80 (27.84)	12.30 (2.97)	132.90 (16.21)
2nd harvest 1994	146.29 (22.32)	163.23 (27.03)	11.94 (3.34)	133.29 (18.54)
Overall mean	131.35 (10.10)	188.03 (16.64)	11.09 (1.05)	124.69 (10.10)
Red kidney beans				
High density 1993	128.80 (25.88)	194.30 (44.50)	15.34 (5.65)	121.80 (19.04)
High density 1994	93.10 (19.79)	263.40 (27.68)	9.98 (3.02)	172.80 (33.70)
Overall mean	110.95 (17.85)	228.85 (34.55)	12.66 (2.68)	147.30 (25.50)
Low density 1993	16.38 (12.22)	4.25 (3.59)	89.75 (10.86)	2.75 (1.68)
Low density 1994	31.75 (16.46)	6.43 (4.71)	88.86 (23.19)	0.71 (0.66)
Overall mean	24.07 (7.69)	5.34 (1.09)	89.31 (0.45)	1.73 (1.02)
Tart cherry				
1993	23.50 (37.83)	6.75 (11.69)	39.75 (13.65)	12.50 (12.52)
1994	47.20 (59.68)	12.20 (14.95)	39.20 (14.08)	45.20 (62.80)
Overall mean	35.35 (11.85)	9.48 (2.73)	39.48 (0.28)	28.85 (16.35)

[a]agriculture
[b]wooded (all wooded types combined)
[c]openings
[d]upland hardwoods
[e]lowland hardwoods
[f]aspen, birch, and associated species
[g]pine and upland conifers
[h]lowland conifers

greatest in evaluation areas in the low deer density area. Evaluation areas around red kidney bean fields in the high deer density area averaged 40.82 fewer wooded hectares than evaluation areas around red kidney bean fields in the low deer density area. Of the 3 crop types, alfalfa field evaluation areas had the least amount of wooded area with a 675.68 ha overall mean (Table 24).

Evaluation areas in the low deer density area had the greatest overall mean area of openings (181.75 ha). Evaluation areas surrounding tart cherry orchards averaged 136.73 ha of openings. The average area of openings in evaluation areas in the high deer density area had a range of 58.40 ha (surrounding red kidney bean fields) to 86.38 ha (around alfalfa fields) (Table 24).

Evaluation areas in the low deer density area had at least 2 to 3 times as many hectares of upland hardwoods as evaluation areas in the high deer density area had. Evaluation areas in the high deer density area had 4 to 5 times as many hectares in lowland hardwoods than the low deer density area (Table 24).

Overall mean aspen and birch area in evaluation areas in the high deer density area ranged from 188.03 ha around alfalfa fields to 228.85 ha around red kidney bean fields. Evaluation areas in the low deer density area had significantly fewer hectares of aspen and birch than evaluation areas in the high deer density area (Table 24).

Evaluation areas in the low deer density area averaged

3 to 8 times more pine and upland conifer area than evaluation areas in the high deer density area. The number of hectares of lowland conifers was much greater in the high deer density area than in the low deer density area. Overall means of lowland conifer areas in the low deer density area ranged from 1.73 ha to 28.85 ha, while the high deer density area ranged from 124.69 ha to 147.30 ha of lowland conifers (Table 24).

The ratio of agricultural area to areas of different vegetation types followed patterns complementary to those found with the number of hectares of different vegetation types (Table 25). The high deer density area had more agricultural area relative to wooded area than the low deer density area. Only 6 evaluation areas had more agricultural area than wooded area: 2 evaluation areas around alfalfa fields, 2 evaluation areas around red kidney bean fields in the high deer density area, 1 evaluation area around red kidney bean fields in the low deer density area, and 1 evaluation area around tart cherry orchards.

Evaluation areas in the low deer density area had more hectares of openings relative to agricultural hectares than evaluation areas in the high deer density area (Table 25). When different wooded areas were categorized into general species associations (Appendix C), evaluation areas in the high deer density area had more agricultural area relative to upland hardwood and pine and upland conifer area, and less agricultural area relative to lowland hardwood, lowland

Table 25. Mean ratios of agricultural area (ha) to areas of different vegetation types (ha) in evaluation areas surrounding alfalfa fields, red kidney bean fields, and tart cherry orchards during 1993 and 1994.

	WD[a] (SE)	OP[b] (SE)	UH[c] (SE)	LH[d] (SE)
Alfalfa				
1st harvest 1993	0.65 (0.05)	7.79 (1.62)	7.08 (1.80)	5.44 (1.01)
2nd harvest 1993	0.68 (0.06)	7.58 (1.74)	8.25 (2.40)	5.08 (0.92)
1st harvest 1994	0.63 (0.05)	10.80 (1.98)	5.83 (1.77)	5.32 (1.02)
2nd harvest 1994	0.65 (0.04)	10.56 (2.10)	6.57 (2.02)	5.21 (1.14)
Overall mean	0.65 (0.02)	9.18 (1.50)	6.93 (0.88)	5.26 (0.13)
Red kidney beans				
High density 1993	0.71 (0.13)	8.88 (2.16)	16.18 (9.93)	5.14 (1.09)
High density 1994	0.56 (0.05)	11.79 (1.82)	3.76 (0.66)	16.13 (7.29)
Overall mean	0.64 (0.08)	10.34 (1.46)	9.97 (6.21)	10.64 (5.50)
Low density 1993	0.54 (0.09)	2.98 (0.85)	1.38 (0.17)	21.54 (3.42)
Low density 1994	0.48 (0.13)	1.67 (0.31)	1.35 (0.38)	10.34 (3.44)
Overall mean	0.51 (0.03)	2.33 (0.66)	1.37 (0.02)	15.94 (5.60)
Tart cherry				
1993	0.36 (0.08)	3.38 (1.68)	1.22 (0.44)	9.68 (1.79)
1994	0.39 (0.05)	5.87 (3.52)	1.00 (0.10)	5.45 (2.61)
Overall mean	0.38 (0.02)	4.63 (1.25)	1.11 (0.11)	7.57 (2.12)

Table 25 (cont'd).

	A/B[e] (SE)	P/UC[f] (SE)	LC[g] (SE)
Alfalfa			
1st harvest 1993	2.70 (0.58)	107.74 (27.47)	4.78 (0.94)
2nd harvest 1993	3.17 (0.77)	102.03 (26.39)	9.97 (4.96)
1st harvest 1994	5.97 (1.80)	72.42 (20.56)	4.82 (0.93)
2nd harvest 1994	6.75 (2.06)	77.64 (23.71)	5.11 (1.06)
Overall mean	4.65 (1.74)	89.96 (15.18)	6.17 (2.20)
Red kidney beans			
High density 1993	6.60 (2.72)	241.19 (112.47)	5.00 (1.14)
High density 1994	1.67 (0.22)	61.80 (30.64)	3.68 (0.97)
Overall mean	4.14 (2.47)	151.50 (89.70)	4.34 (0.66)
Low density 1993	83.03 (11.64)	4.57 (0.94)	128.32 (24.86)
Low density 1994	51.08 (12.02)	5.94 (1.52)	462.58 (85.75)
Overall mean	67.06 (15.98)	5.26 (0.69)	295.45 (167.13)
Tart cherry			
1993	33.70 (5.79)	13.85 (5.91)	18.20 (5.41)
1994	21.03 (10.44)	6.18 (1.63)	5.68 (2.48)
Overall mean	27.36 (6.34)	10.02 (3.84)	11.94 (6.26)

[a]wooded areas (all types combined)
[b]openings
[c]upland hardwoods
[d]lowland hardwoods
[e]aspen, birch, and associated species
[f]pine and upland conifers
[g]lowland conifers

conifer, and aspen and birch area than the low deer density area.

Edge diversity indices (Patton 1975) were calculated for the different vegetation types within each evaluation area. Each index is relative to a circle's index of 1.0. Evaluation areas around tart cherry orchards had the most agricultural edge relative to interior crop area with an average edge diversity index of 8.09 (Table 26). Evaluation areas surrounding alfalfa fields followed with an overall mean edge diversity index associated with agricultural area of 6.46. Agricultural areas within evaluation areas around red kidney bean fields in the high deer density area had the same average edge diversity index as agricultural areas had in evaluation areas surrounding red kidney bean fields in the low deer density area (Table 26).

Evaluation areas in the high deer density area had the greatest mean edge diversity indices associated with wooded areas (Table 26). This reflected the lower mean agriculture to wooded ratios. The range between the high and the low deer density areas was relatively small (8.60 to 11.51).

There was also a relatively small mean edge diversity index range for open areas (Table 26). Tart cherry orchard evaluation areas had the highest overall mean index for openings (5.63) and red kidney bean field evaluation areas in the low deer density areas had the lowest mean edge diversity index for openings (6.40) (Table 26).

Mean edge diversity indices associated with upland

Table 26. Mean edge diversity indices (Patton 1975) associated with different vegetation types in evaluation areas surrounding alfalfa fields, red kidney bean fields, and tart cherry orchards during 1993 and 1994.

	AG[a] (SE)	WD[b] (SE)	OP[c] (SE)	UH[d] (SE)
Alfalfa				
1st harvest 1993	4.91 (0.25)	10.72 (0.32)	4.59 (0.22)	3.14 (0.43)
2nd harvest 1993	5.15 (0.35)	11.47 (0.65)	4.75 (0.30)	3.34 (0.48)
1st harvest 1994	7.61 (2.21)	11.33 (0.59)	4.65 (0.38)	3.98 (0.29)
2nd harvest 1994	8.15 (2.57)	11.71 (0.66)	4.75 (0.44)	4.02 (0.33)
Overall mean	6.46 (1.44)	11.31 (0.37)	4.69 (0.07)	3.62 (0.39)
Red kidney beans				
High density 1993	5.22 (0.57)	12.74 (0.97)	5.52 (0.57)	3.71 (0.58)
High density 1994	5.54 (0.29)	10.27 (0.26)	3.75 (0.17)	4.18 (0.28)
Overall mean	5.38 (0.16)	11.51 (1.24)	4.64 (0.89)	3.95 (0.24)
Low density 1993	5.75 (0.56)	9.00 (0.60)	4.51 (0.19)	4.45 (0.30)
Low density 1994	4.98 (0.18)	8.19 (0.24)	4.62 (0.11)	4.45 (0.16)
Overall mean	5.37 (0.29)	8.60 (0.41)	4.60 (0.63)	4.20 (0.30)
Tart cherry				
1993	7.98 (0.57)	10.40 (1.05)	5.77 (0.49)	5.67 (0.50)
1994	8.19 (1.40)	9.97 (1.05)	5.49 (0.53)	6.06 (0.59)
Overall mean	8.09 (0.11)	10.19 (0.22)	5.63 (0.14)	5.87 (0.20)

Table 26 (cont'd).

	LH[e] (SE)	A/B[f] (SE)	P/UP[g] (SE)	LC[h] (SE)
Alfalfa				
1st harvest 1993	4.68 (0.47)	5.18 (0.44)	2.06 (0.34)	4.14 (0.62)
2nd harvest 1993	5.38 (0.67)	5.40 (0.44)	2.18 (0.31)	4.22 (0.28)
1st harvest 1994	5.06 (0.54)	5.10 (0.27)	2.52 (0.21)	4.33 (0.32)
2nd harvest 1994	5.43 (0.58)	5.16 (0.30)	2.38 (0.22)	4.51 (0.36)
Overall mean	5.14 (0.30)	5.21 (0.11)	2.29 (0.18)	4.30 (0.14)
Red kidney beans				
High density 1993	5.99 (0.84)	4.88 (0.36)	2.41 (0.55)	5.15 (0.58)
High density 1994	3.64 (0.36)	5.65 (0.22)	1.93 (0.39)	3.99 (0.39)
Overall mean	4.82 (1.18)	5.27 (0.39)	2.17 (0.24)	4.57 (0.58)
Low density 1993	0.73 (0.47)	0.28 (0.17)	4.24 (0.43)	0.20 (0.19)
Low density 1994	1.37 (0.48)	0.35 (0.21)	4.05 (0.31)	0.61 (0.56)
Overall mean	1.05 (0.32)	0.32 (0.04)	4.15 (0.10)	0.41 (0.21)
Tart cherry				
1993	1.39 (0.48)	2.64 (0.68)	3.45 (0.20)	1.20 (0.54)
1994	1.74 (0.53)	2.57 (0.62)	16.12 (10.74)	1.46 (0.57)
Overall mean	1.57 (0.18)	2.61 (0.04)	9.79 (6.34)	1.33 (0.13)

[a]agriculture
[b]wooded areas (all types combined)
[c]openings
[d]upland hardwoods
[e]lowland hardwoods
[f]aspen, birch, and associated species
[g]pine and upland conifers
[h]lowland conifers

hardwood stands and with lowland hardwood stands reflected the average number of hectares present in evaluation areas in both the high and the low deer density areas. Upland hardwood and pine and upland conifer mean edge diversity indices were greatest in the evaluation areas in the low deer density area (Table 26). Lowland hardwood, lowland conifer, and aspen and birch stands had greater mean edge diversity indices in the high deer density areas than the low deer density area.

Vegetation types that had the greatest average edge diversity indices also had the greatest mean perimeter lengths for all wooded types combined, upland hardwoods, lowland hardwoods, aspen and birch, and lowland conifers (Tables 26 and 27). Agricultural areas in alfalfa field evaluation areas had the greatest mean perimeter length, reflecting the relatively large number of agricultural hectares. Areas around red kidney bean fields in the high deer density area had the greatest average wooded perimeter length with about 4,000 m more perimeter than the low deer density area.

Evaluation areas in the low deer density area had the greatest mean perimeter length for pine and upland conifer stands (Table 27). Evaluation areas around red kidney bean fields in the high deer density area had 11,800 fewer meters of pine and upland conifer perimeter than red kidney bean evaluation areas in the low deer density area. Evaluation areas around alfalfa fields had the least amount of pine and

Table 27. Mean perimeter lengths (in meters) of different vegetation types in evaluation areas surrounding alfalfa fields, red kidney bean fields, and tart cherry orchards during 1993 and 1994.

	AG[a] (SE)	WD[b] (SE)	OP[c] (SE)	UH[d] (SE)
Alfalfa				
1st harvest 1993	36055 (2258)	98365 (3899)	14460 (1714)	11419 (2656)
2nd harvest 1993	38582 (3446)	104261 (5358)	17048 (2969)	11467 (2586)
1st harvest 1994	57672 (18987)	104951 (5172)	14986 (2495)	16078 (2155)
2nd harvest 1994	62834 (22060)	107510 (5806)	16046 (2845)	15481 (2409)
Overall mean	48786 (11646)	103771 (3348)	15635 (996)	13611 (2179)
Red kidney beans				
High density 1993	37751 (3920)	116280 (8759)	18283 (3830)	13020 (2940)
High density 1994	38412 (2554)	97991 (3311)	8096 (743)	16739 (2049)
Overall mean	38082 (331)	107136 (9145)	13190 (5094)	14880 (1860)
Low density 1993	38127 (4678)	85021 (6602)	20340 (2004)	25124 (1541)
Low density 1994	31775 (3683)	31775 (3683)	23116 (842)	26262 (2019)
Overall mean	34951 (3176)	58398 (26623)	21728 (1388)	25693 (569)
Tart cherry				
1993	45220 (10034)	91526 (10757)	22240 (4999)	41614 (2809)
1994	43065 (7217)	99096 (10263)	24012 (4176)	36763 (4966)
Overall mean	44142 (1078)	95311 (3785)	23126 (886)	39189 (2426)

Table 27 (cont'd).

	LH[e] (SE)	A/B[f] (SE)	P/UC[g] (SE)	LC[h] (SE)
<u>Alfalfa</u>				
1st harvest 1993	18840 (3932)	26942 (3532)	2523 (729)	14460 (1714)
2nd harvest 1993	22414 (4434)	27340 (3517)	2583 (655)	15257 (1735)
1st harvest 1994	22417 (3905)	23949 (2674)	3123 (529)	17504 (1782)
2nd harvest 1994	24992 (4278)	23167 (2982)	2910 (566)	18195 (2000)
Overall mean	22166 (2189)	25350 (1818)	2785 (245)	16354 (1541)
<u>Red kidney beans</u>				
High density 1993	25336 (6164)	23910 (4206)	3937 (1440)	20011 (3295)
High density 1994	12902 (2519)	32271 (2345)	2545 (723)	18170 (2689)
Overall mean	19119 (6217)	28091 (4181)	3241 (696)	19091 (921)
Low density 1993	2167 (1578)	458 (265)	14615 (2278)	240 (224)
Low density 1994	3508 (1699)	551 (346)	13416 (2716)	481 (446)
Overall mean	2838 (671)	505 (47)	14016 (600)	361 (121)
<u>Tart cherry</u>				
1993	2879 (4177)	1599 (2769)	7511 (1613)	2121 (2127)
1994	4969 (5607)	2825 (2984)	12674 (2882)	4600 (2881)
Overall mean	3924 (1045)	2212 (613)	10093 (2582)	3360 (1240)

[a]agriculture
[b]wooded (all wooded types combined)
[c]openings
[d]upland hardwoods
[e]lowland hardwoods
[f]aspen, birch, and associated species
[g]pine and upland conifers
[h]lowland conifers

upland conifer perimeter length.

Average perimeter lengths associated with lowland hardwood, lowland conifer, and aspen and birch stands were greater in evaluation areas located in the high deer density area than in evaluation areas within the low deer density area (Table 27). The high deer density area had 27,586 m more perimeter around aspen and birch stands, 18,730 m more perimeter around lowland conifer stands, and 16,281 m more perimeter around lowland hardwood stands.

Influential Field and Landscape Variables and Predictive Crop Loss Models

Each field and landscape variable was tested for its ability to explain crop loss intensities for all 3 crop types. Variables that had positive (+) or negative (-) Pearson's correlation coefficients at ($P \leq 0.20$) are presented in tables for each crop type. Categorical variables that were tested for significance ($P \leq 0.10$) with one-way analysis of variance (Sprinthall 1990) or unpaired t-tests ($P \leq 0.10$, 2-tailed, Sprinthall 1990) are listed in tables with a "*" and their respective significance level.

Results about the variables that influenced crop losses and the predictive crop loss models are presented in 3 sections, 1 section for each crop type. Within each crop type's section, results of field and landscape variables that were significantly correlated ($P \leq 0.20$) with production levels are presented before the predictive crop models. Variables that were more highly correlated ($P \leq 0.10$) with crop production levels or browse percentages are presented with their respective significance levels in the text.

Production losses in alfalfa fields and in red kidney bean fields were recorded as negative numbers. Therefore, negatively correlated variables indicated greater crop loss as independent variable values increased. Positive correlations indicated greater crop loss as the independent variable values decreased. Percentages of browsed CAG twigs in orchards were recorded as positive numbers; positive correlations indicated greater browse percentages when independent variable values increased, and negative correlations indicated greater browse percentages as independent variable values decreased.

Some of the variables that were listed for both alfalfa and red kidney bean fields were not listed for tart cherry orchards because the small number of orchards did not provide sufficient information to generate correlations or because orchardists used the same crop management practices, such as fertilizer application or repellent use. Red kidney bean field variables had 2 more fertilizer variables than alfalfa fields did because more detailed information was available about fertilizing practices in red kidney bean fields. Irrigation variables were used only for red kidney bean fields.

Field and Landscape Variables That Influenced Production Levels in Alfalfa Fields

The first harvests during 1993 and 1994 and the second harvests during 1993 and 1994 were combined because results and literature indicated that deer can use alfalfa fields differently between harvest periods. By the time the second harvest was growing, thermal cover no longer influenced deer behavior regarding the physiological need for cover from cold temperatures (Rogers 1981, Murphy et al. 1985, Bender and Haufler 1987, unpubl.). Also, most does have had their fawns and begin to regroup with other deer (Hirth 1977), and the seasonal availability of food, which governs what deer eat and when they eat it (McCaffery et al. 1974), has changed. In addition, precipitation levels had no statistically significant correlations ($P \geq 0.50$ for alfalfa and $P \geq 0.40$ for red kidney beans in the high deer density area) so weather related growing conditions between years were not considered to have been a significant influence on crop losses.

Most of the significantly correlated variables indicated that production losses increased when more wooded area was present, especially if wooded areas contained highly selected forage species (such as aspen or maple species) or if thermal cover stands were near fields (average distance was 300 m). Production losses also increased when spring food quality increased.

Influential Alfalfa Field Variables

For each alfalfa harvest, there were large numbers of variables that varied with differences in paired plot production at $P \leq 0.20$ (Table 28). Some of the relationships between field variables and differences in paired plot production suggest trends of how variables might have influenced production losses in alfalfa fields.

Field morphology showed some relationships with different levels of alfalfa loss (Table 28). During 1993's second harvest, larger fields had less production ($P \leq 0.005$). During 1993's first harvest, there was less production in fields that had shorter perimeter lengths, but during the second harvest of that year, less alfalfa production occurred in fields that had longer perimeter lengths ($P \leq 0.03$).

All 3 edge categories (agriculture, wooded, and development) correlated with paired plot production differences for at least 1 of the harvests during 1993 and 1994 (Table 28). The percent of field perimeter bordered by agriculture and by development varied positively with paired plot production differences for the first harvests during 1993 and 1994 ($P \leq 0.01$ for 1994), although neither of these 2 edge categories had statistically significant production

Table 28. Significant correlations (P ≤ 0.20) between differences in alfalfa paired plot production and field and landscape variables for first, second, and combined harvests during 1993 and 1994 in northern lower Michigan.

Variable	H193[a]	H293[b]	H194[c]	H294[d]	H1[e]	H2[f]
<u>Field variables</u>						
field size (ha)		-				-
perimeter length around field (m)	+	-			+	-
presence of hill(s) in field	*					
% of field perimeter adjacent to agricultural areas			+		+	
% of field perimeter adjacent to wooded areas			-		-	
% of field perimeter adjacent to development areas	+					
number of days exclosures were in field			-			
number of deer sighted in field				-		-
number of deer beds sighted in field			-		-	
% block permits used			-		-	
<u>Landscape variables</u>						
area (ha) of different vegetation types in evaluation area:						
agriculture		-	+		+	-
wooded (all wooded types combined)			-		-	
openings	+	+	+		+	+
upland hardwood	-				-	
lowland hardwood	+				+	
aspen/birch		-	-		-	-

Table 28 (cont'd).

Variable	H193	H293	H194	H294	H1	H2
pine/upland conifer	−		−		−	
lowland conifer		+		+		+
perimeter length (m) of different vegetation types in evaluation areas:						
openings	+		+		+	
upland hardwood	−					
lowland hardwood		+	+		+	+
aspen/birch		−	−		−	−
pine/upland conifer	−		−		−	
lowland conifer	+					
edge index for different vegetation types in evaluation area:						
openings	+				+	
upland hardwood	−					
lowland hardwood	−		+		+	
pine/upland conifer			−		−	
lowland conifer	+					
ratio of agriculture to different vegetation types in evaluation area:						
agriculture to wooded (all wooded types combined)		−	+		+	−
agriculture to openings	−					
agriculture to upland hardwoods	+	−	+	+	+	
agriculture to lowland hardwoods	−	−				
agriculture to aspen/birch					+	
agriculture to pine/upland conifer	+		+		+	

Table 28 (cont'd).

Variable	H193	H293	H194	H294	H1	H2
agriculture to lowland conifer		+	+		+	
HSI values:						
HSI spring food			+	-		
HSI security cover	+					-
SI values:						
SI open	+					
SI agriculture (fall/winter)	-					
SI agriculture (spring)	-			-		
SI security cover with agriculture included			-		-	
vegetative characteristics:						
stem density (per ha)				+		
basal area (m^2/ha)						
mean horizontal cover	+					
mean vertical cover			+	+		
distance measurements:						
distance to nearest thermal cover stand (M4V1)			+		+	

[a]first harvest 1993
[b]second harvest 1993
[c]first harvest 1994
[d]second harvest 1994
[e]first harvests combined
[f]second harvests combined
[+]positive Pearson's correlation coefficient ($P \le 0.20$, Sprinthall 1990)
[-]negative Pearson's correlation coefficient ($P \le 0.20$)
[*]significant $P \le 0.05$ (unpaired t-test, Sprinthall 1990)

differences for those 2 harvests. There was less ($P < 0.005$) production during the first 1994 harvestas the percent of field edge adjacent to wooded areas increased.

Only the first 1993 harvest had statistically significant ($P \leq 0.05$) crop loss when hills were present in the fields. The first harvest during 1994 had 63.37 kg/ha and the second harvests of 1993 and 1994 combined had an average of 18.90 kg/ha more production loss in fields that had no hills (none of the differences were statistically significant, $P > 0.10$).

Pesticide and herbicide use showed no trends or statistically significant relationships ($P > 0.10$) with paired plot production differences. Both of the 1993 harvests and the first 1994 harvest had more production loss, ranging from 59.99 kg/ha to 133.96 kg/ha, in fields that had fertilizer applied than in those that did not. None of the differences were statistically significant.

No statistically significant differences ($P > 0.10$) in paired plot production were detected among seed varieties (Jake's, Pioneer, grass mixes, vernal, and a miscellaneous category of mixed varieties). The number of years alfalfa was seeded also showed no relationship with production differences between paired plots.

The amount of crop production loss due to deer did not differ statistically among crop damage control methods (no method, summer shooting only, block permit only, or both permits used). The first harvest during 1994 showed less production when the percentage of block permits used by landowners was greater.

The number of days exclosures were in fields and the number of deer beds seen in fields were negatively correlated with paired plot production differences during 1994's first harvest (Table 28). The number of deer sighted in fields from early April through mid-October (1993 and 1994) was negatively correlated with differences between paired plot production during the second 1994 harvest.

When fields were grouped based on their general geographic location (Figure 3), no statistically significant differences ($P > 0.10$) between paired plot production were detected among locations, although some trends seemed evident. For 1993's first harvest, there was a north to south decrease in production loss. The Hillman area (Montmorency County) had no mean production loss (n=3), the tri-county area (the intersection of Alpena, Montmorency, and Presque Isle counties) had an 18.13 kg/ha mean loss (n=4), the Hawks area (Presque Isle County) had a 207.45 kg/ha mean loss (n=2), and the Moltke area (Presque Isle County) had a 289.35 kg/ha mean loss (n=2).

Other areas included in the geographic grouping were the Ossineke area (Alpena County), the Reider School Road and Salina Road area (Alpena County), and the Millersburg area (Presque Isle County). When production losses were ranked (1=most loss, 7= least loss) for each harvest, the Hillman area consistently ranked 5 to 7 with an average of

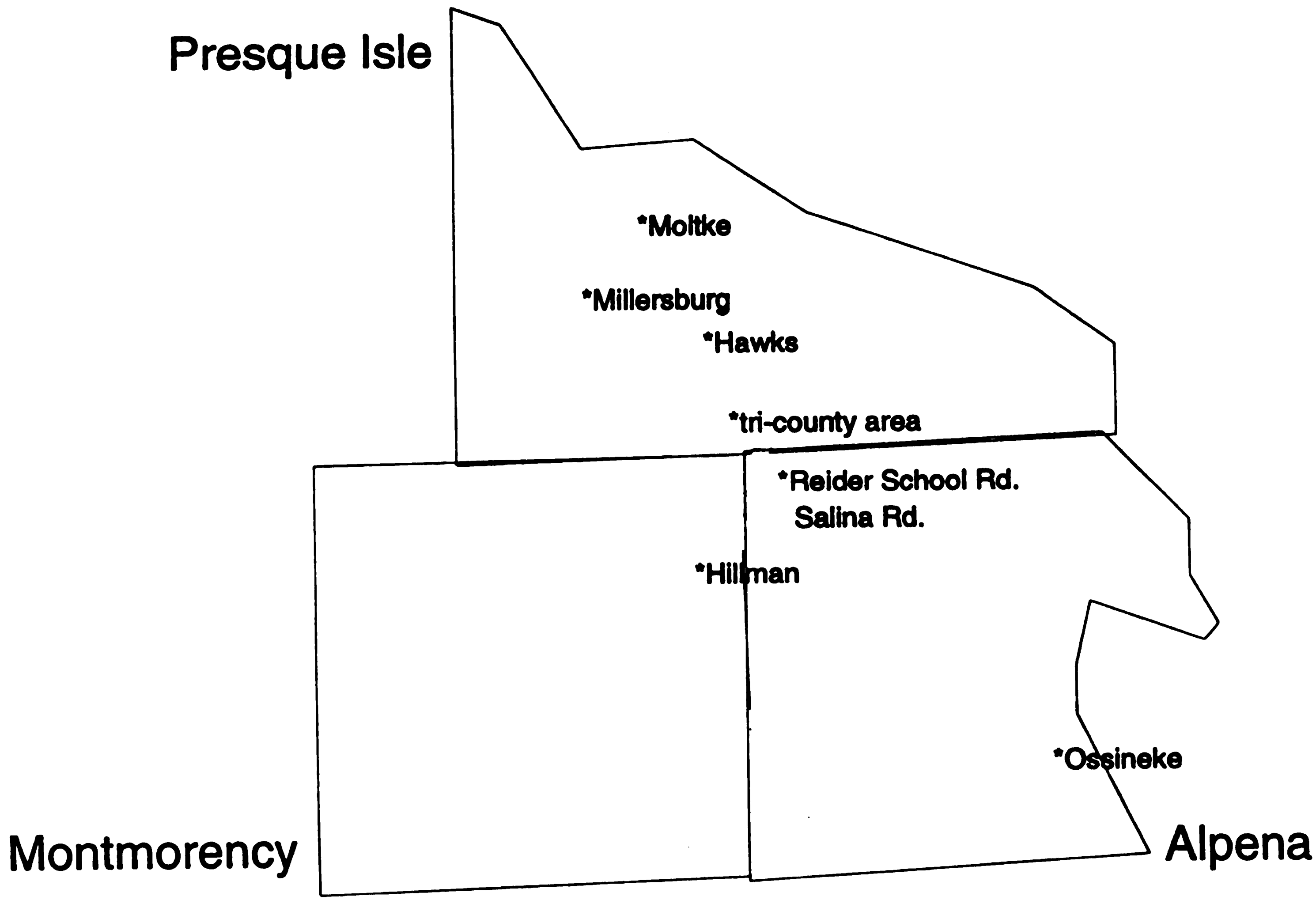

Figure 3. General geographic field locations for alfalfa fields in northern lower Michigan during 1993 and 1994.

0.0 kg/ha production loss (n=4), the tri-county area ranked 1 to 3 with losses averaging 313.7 kg/ha (n=5), the Moltke area ranked 1 to 3 for 3 harvests with an average loss of 210.24 kg/ha (n=5), and the Hawks area ranked second for both 1993's and 1994's first harvest with a 246.21 kg/ha average production loss (n=8).

Influential Landscape Variables in Evaluation Areas Surrounding Alfalfa Fields

None of the harvests showed statistically significant relationships between precipitation levels and paired plot production differences ($P \geq 0.50$). Only the second 1993 harvest suggested greater production loss when there was less precipitation during the time alfalfa was growing (Appendix F). There were no trends evident in similar plots for 1993's first harvest or for 1994's first and second harvests.

Categorical landscape variables consisted of the use of lure crops or supplemental feeding and road type nearest to fields. Results from the first 1994 harvest showed there was less alfalfa production when landowners fed deer, but results were skewed by 1 field. When that field was dropped from the analysis, the 1 other field near which supplemental feeding was practiced had a mean production loss of 155.80 kg/ha. Road types showed no statistically significant relationships with paired plot production differences ($P > 0.10$) for any of the alfalfa harvests.

For 1994's first harvest, there was less production losses when there were fewer agricultural hectares in evaluation areas ($P \leq 0.004$) (Table 28). Conversely, production was less during the second 1993 harvest when there was more agricultural area in evaluation areas. Production was less during 1994's first harvest when the amount of wooded area increased ($P \leq 0.003$) in relation to the amount of agricultural area present in evaluation areas. The opposite was true for the second harvest of 1993 when less production occurred in areas that had less wooded area relative to agricultural area.

There was less production during the first harvests of 1993 and 1994 when there was less open area ($P \leq 0.03$ for 1993) and the perimeter length of openings was shorter ($P \leq 0.02$ for 1993). Similarly, the first harvest of 1993 also showed less alfalfa production when the edge diversity index associated with openings was lower and when there was less open area relative to the area of agricultural land ($P \leq 0.02$).

For the first harvest during 1993, production was less when the area, perimeter length, and edge diversity index of upland hardwoods was greater (Table 28). For the first harvests of both years and for the second 1994 harvest, production was less when agricultural area decreased relative to upland hardwood area ($P \leq 0.01$ for 1994's first harvest). The converse occurred for the second harvest during 1993 where less production occurred when there was more agricultural area relative to upland hardwood area.

There was less production during 1993's first harvest when both the area and the edge diversity indices associated with lowland hardwoods decreased. The first 1994 harvest had the opposite correlation with paired plot production differences and lowland hardwood edge diversity indices. Both 1993's second harvest ($P \leq 0.004$) and 1994's first harvest had less production when the perimeter length of lowland hardwood stands was shorter. For both of the 1993 harvests, production was less when agricultural area increased relative to lowland hardwood area ($P \leq 0.02$ for the second 1993 harvest). There was less production for the first harvest of 1994 and for the second harvest of 1993 when the area and perimeter length of aspen and birch stands increased within evaluation areas (Table 28).

During the first harvests of 1993 and 1994, less production occurred when the area and perimeter length of pine and upland conifer stands were greater ($P \leq 0.004$ for perimeter length during 1994's first harvest). The first 1994 harvest also had more production loss when the edge diversity index associated with pine and upland conifer stands was lower ($P \leq 0.02$). For the first harvests during 1993 and 1994, production was less when the area of pine and upland conifer stands was a greater proportion of the area of agriculture (Table 28). All significant correlations between paired plot production differences and variables associated with lowland conifer stands were positive (Table 28). Alfalfa production was less for 1993 and 1994 second harvests when there was less lowland conifer area in evaluation areas. The first harvest of 1993 had less production when the perimeter length of lowland conifer stands was shorter ($P \leq 0.02$) and when the edge diversity index associated with lowland conifer areas was lower. The second 1993 harvest and the first 1994 harvest had less production when evaluation areas had more lowland conifer area relative to agricultural area.

Habitat suitability indices and SI's had a mix of significant relationships with paired plot production differences (Table 28). During 1993's first harvest, production was less when security cover quality decreased during 1993's first harvest. There was less production when spring food HSI's were lower during the first harvest in 1994, but there was greater production when spring food HSI's were lower during that year's second harvest ($P \leq 0.05$).

When SI's for openings were lower, production was less during 1993's first harvest. The first harvest during 1993 also had less production when fall and winter food SI's for agricultural area were higher. Less production occurred during 1994's second harvest and 1993's first harvest when the quality of spring food provided by agricultural areas was greater. Suitability indices for security cover that included agricultural crops showed that less crop production occurred when security cover values were higher during 1994's first harvest.

Many woodland plant characteristics in evaluation areas surrounding alfalfa fields had positive correlations with production loss (Table 28). During 1994's second harvest, production was less when stem densities were lower in areas around alfalfa fields. The first harvest and the second harvest during 1994 had less production when the average percent of vertical cover was lower. Production was also less when mean horizontal cover percentages were lower during 1993's first harvest (Table 28).

The only distance measurement that showed a significant correlation with alfalfa crop loss was the distance from alfalfa fields to the nearest thermal cover stand (Table 28). During 1994's first harvest, there was less production when the distance from alfalfa fields to thermal cover stands was shorter.

Six variables showed significant correlations with differences between paired plot production during both first harvests (Table 28): area of openings, perimeter length of openings, perimeter length of pine and upland conifer stands, edge diversity indices associated with lowland hardwood areas, proportion of agricultural area to pine and upland conifer area, and proportion of agricultural area to upland hardwood area. The area of lowland conifers and the proportion of agriculture to upland hardwoods were 2 variables that significantly correlated with paired plot production differences during 1993's second harvest and 1994's second harvest.

Influential Field and Landscape Variables for Combined First Harvests and for Combined Second Harvests

When data were combined for the first 1993 harvest and the first 1994 harvest, and combined for the second 1993 harvest and the second 1994 harvest, many of the significant correlations that were elicited in individual harvests were also statistically significant for the combined harvests (Table 28). Two field variables showed trends; the presence of hills in fields and fertilizer use. The first harvests had 64.26 kg/ha less production when hills were present in fields. The combined first harvests also had 107.44 kg/ha less alfalfa production when fertilizer was used on the fields, while the combined second harvests had 43.0 kg/ha less production in fields that had no hills.

For the first harvests combined, there was less production when field perimeter length was shorter and when there was a lower percent of field perimeter adjacent to agriculture. When more deer beds were observed in fields and the percent of block permits used was higher, there was less production (Table 28).

For the combined second harvests, less alfalfa was produced when the number of deer sighted in fields was higher. The combined second harvest results showed opposite correlations with field perimeter length than the first harvests showed. During the second harvests, there was less production when field perimeter lengths were longer and when fields were larger (Table 28).

The first harvests showed less crop production when there was less agricultural area ($P \leq 0.003$), opening area ($P \leq 0.01$), and lowland hardwood area present inside evaluation areas (Table 28). Production was also less when evaluation areas had more wooded area ($P \leq 0.001$), upland hardwood area, aspen and birch area ($P \leq 0.004$), and pine and upland conifer area.

Significant correlations between paired plot production differences and both perimeter lengths and edge diversity indices were related to the significant correlations between production levels and the area associated with the different vegetation types (Table 28). Less production occurred when perimeter lengths for openings ($P \leq 0.03$) and for lowland hardwood stands ($P \leq 0.04$) were shorter (edge diversity indices associated with these 2 variables also varied positively with differences between paired plot production). Less production also occurred when perimeter lengths were longer for aspen and birch stands ($P \leq 0.04$) and for pine and upland conifer stands ($P \leq 0.0005$) (edge diversity indices associated with pine and upland conifer stands also negatively correlated with paired plot production differences).

For the second harvests, there was less production when there was more agricultural area and aspen and birch area and less opening area and lowland conifer area (Table 28). Alfalfa fields produced less when perimeter lengths were longer for aspen and birch stands ($P \leq 0.01$), while production was greater when perimeter lengths of lowland hardwood stands were longer ($P \leq 0.03$).

There was less production during the first harvests when evaluation areas surrounding alfalfa fields had more wooded area ($P \leq 0.01$), upland hardwood area ($P \leq 0.004$), aspen and birch area, pine and upland conifer area, and lowland conifer area relative to agricultural area (Table 28). Only 1 proportion variable significantly correlated with paired plot production differences for the combined second harvests; production was less when wooded area decreased relative to agricultural area (Table 28).

During the second harvests, less production occurred when HSI's for security cover were greater. The first harvests of 1993 and 1994 had less alfalfa production when SI's were higher for security cover that included agricultural areas. Distance from alfalfa fields to the nearest thermal cover stand (M4V1 in the HSI model) was the only distance variable that was significantly correlated with production loss. For the first harvests, production was less when the distance to the nearest 2.0 ha thermal cover stand was shorter (Table 28).

Predictive Alfalfa Crop Loss Models

First Harvest During 1993

Paired plot production differences were best predicted with 6 variables ($n=69$, $R^2=0.994$, $P < 0.0002$) (Table 29). The prediction equation was (in order of variables listed in Table 29): paired plot production difference (kg/ha dry matter) = $-1397.16 + 0.04X_1 + 0.43X_2 + 15.65X_3 + 746.23X_4 - 166.69X_5 - 17.64X_6$. There was less production when field perimeter lengths and perimeter lengths of open areas were shorter, when SI's for openings were lower, and when there was less pine and upland conifer area present in evaluation areas. There was also less alfalfa production when SI's for agriculture during the spring and the edge diversity index for lowland hardwood stands were higher.

Observed differences in paired plot production were plotted with predicted differences from regression model output (Append G). The largest difference between observed and predicted production differences was 24.10 kg/ha and the smallest difference was 0.65 kg/ha. Overall, this model effectively predicted differences in paired plot production.

Table 29. Variables that best described paired plot production differences for the first alfalfa harvest during 1993 in northern lower Michigan.

Variable	Correlation	Partial r^2
perimeter length of openings	+	0.499
field perimeter length	+	0.267
area of pines and upland conifers	+	0.141
SI for openings	+	0.056
SI for agriculture during the spring	-	0.016
edge diversity index associated with lowland hardwood areas	-	0.015

First Harvest During 1994

Paired plot production differences were best predicted by 8 variables (n=69) that had an R^2=0.942 ($P \leq 0.0001$) (Table 30). The prediction equation was (in order of variables listed in Table 30): paired plot production difference (kg/ha dry matter) = $3743.90 - 3126.20X_1 + 36.94X_2 - 3126.20X_3 + 3.38X_4 - 0.009X_5 + 0.35X_6 - 32.17X_7 + 3.72X_8$. There was less production when there was more wooded area (all wooded types combined) and less pine and upland conifer area, and when there was less agricultural area within evaluation areas. Similarly, there was less production when there was less wooded area and lowland conifer area and more upland conifer area available relative

Table 30. Variables that best described paired plot production differences for the first alfalfa harvest during 1994 in northern lower Michigan.

Variable	Correlation	Partial r^2
area of woodlands	-	0.396
proportion of agriculture to upland hardwoods	+	0.189
proportion of agriculture to woods	-	0.126
area of agriculture	+	0.074
perimeter length of lowland hardwood stands	-	0.066
distance to nearest thermal cover stand	+	0.040
proportion of agriculture to lowland conifers	-	0.038
area of pines and upland conifers	+	0.013

to agricultural area. As the distance from fields to thermal cover stands decreased, production loss was greater.

Observed and predicted paired plot production differences were plotted with negative numbers representing crop loss (Appendix G). The smallest difference between a predicted value and an observed value was 4.62 kg/ha and the largest difference was 73.71 kg/ha.

First Harvests Combined (1993 and 1994)

An R^2=0.696 ($P \leq 0.0001$) was calculated when the 1993 and the 1994 first harvest data sets were merged together (Table 31). The predictive equation was (in order of variables listed in Table 31): paired plot production differences (kg/ha dry matter) = $3174.82 - 3.89X_1 + 17.07X_2 - 3.89X_3 - 1.52X_4 + 2.29X_5$. With this model, there was less production when there was less agricultural area, more wooded area, and a greater percentage of used block permits. Production was also lower when the area upland hardwoods increased relative to agricultural area and when the area of woods decreased relative to agricultural area.

Table 31. Variables that best described paired plot production differences for the 1993 and 1994 first harvests combined in northern lower Michigan.

Variable	Correlation	Partial r^2
area of woodlands	-	0.305
proportion of agriculture to upland hardwoods	+	0.189
proportion of agriculture to woods	-	0.115
percent used block permits	-	0.047
area of agriculture	+	0.041

Neither the 1993 or the 1994 first harvest model identified the percentage of block permits used by landowners as a predictor variable. The combined model did not have any of the same variables as the 1993 first harvest model, but it had 4 variables that were selected for the 1994 first harvest model. The amount of agricultural area and the proportion of agricultural area to upland hardwoods positively correlated with differences between paired plot production in both models The proportion of agriculture to woodlands and the area of agriculture positively correlated with paired plot production differences in both models (Tables 30 and 31).

Predicted paired plot production differences from the combined first harvest model had greater differences with the observed paired plot production differences than the 1993 or the 1994 first harvest model (Appendix G). The best predicted estimate was 7.92 kg/ha from the observed value. The largest difference was 173.47 kg/ha.

No variables were selected as being statistically significant variables when 1993's first harvest paired plot production differences estimates were tested with the combined harvest model. Production differences from the first 1994 harvest had an R^2=0.784 when it was tested with the combined model.

The 6 correlations that were shared by the 1993 first harvest and the 1994 first harvest (opening area, opening perimeter length, pine and upland conifer perimeter length, edge diversity index of lowland hardwood stands, the proportion of agricultural area to pine and upland conifer area, and the proportion of agricultural area to upland hardwood area) were added to the combined model to test if they increased its predictive ability using the individual 1993 and 1994 first harvest production differences. The predictive ability of the combined first harvest model increased from 0.0 to R^2= 0.600 using 1993's first harvest data when 2 of the 6 significantly correlated variables were selected through stepwise procedures. The area of openings and the proportion of agricultural area to upland hardwood area had an R^2=0.600 with 1993's first harvest production estimates. There was less production when there was less open area and more upland hardwood area relative to agricultural area.

The R^2 increased to 0.912 when 1994's first harvest data were tested with the combined harvest model that had 2 of the 6 shared variables selected into the model. The 2 variables indicated less production when perimeter lengths of open areas were longer and when agricultural area decreased relative to pine and upland conifer area.

Second Harvest During 1993

The best regression model identified 4 variables (n=69) for 1993's second harvest (R^2=0.843, $P \leq 0.0002$) (Table 32).

Table 32. Variables that best described paired plot production differences for the second alfalfa harvest during 1993 in northern lower Michigan.

Variable	Correlation	Partial r^2
area of aspen and birch	-	0.620
proportion of agriculture to woods	-	0.101
proportion of agriculture to lowland conifers	-	0.071
area of agriculture	+	0.050

The predictive equation was (in order of variables listed in Table 32): paired plot production difference (kg/ha dry matter) = $- 288.76 - 0.0002X_1 - 2160.53X_2 - 2.81X_3 + 4.81X_4$. There was less production when wooded area decreased relative to agricultural area. Alfalfa production was less when the area of aspen and birch was greater and when the area of lowland conifers decreased relative to agricultural area. Production was less when there were fewer agricultural hectares present in evaluation areas.

Predicted paired plot production differences were generated from regression output (Appendix H). The smallest difference between an observed and a predicted value was 1.62 kg/ha. The greatest difference was 145.92 kg/ha.

Second Harvest During 1994

An R^2=0.662 ($P \leq 0.002$) was generated with 3 variables (n=69) (Table 33). The predictive equation was (in order of variables listed in Table 33): paired plot production difference (kg/ha dry matter) = $138.95 - 6.76X_1 + 7.47X_2 - 344.33X_3$. There was less production when agricultural area decreased relative to upland hardwood area and as HSI's for spring food increased. Production was also less when more deer were seen in fields.

This model had a lower R^2 value than the 1993 first harvest model, the first 1994 first harvest model, and the 1994 second harvest model. The smallest difference between observed and predicted values was 4.09 kg/ha and the greatest difference was 92.54 kg/ha (Appendix H).

Table 33. Variables that best described paired plot production differences for the second alfalfa harvest during 1994 in northern lower Michigan.

Variable	Correl-ation	Partial r^2
number of deer sighted in fields	-	0.262
proportion of agriculture to upland hardwoods	+	0.200
HSI for spring food	-	0.199

Second Harvests Combined (1993 and 1994)

When the second harvest during 1993 and 1994 were combined, the best regression model identified 2 variables. Alfalfa production was less when evaluation areas had more aspen and birch area (partial r^2=0.209). Similar to the 1994 second harvest model, production was less when more deer were seen in alfalfa fields (partial r^2= 0.169). These 2 variables generated a comparatively low R^2=0.378 ($P \leq 0.0008$). The predictive equation was (in the order presented above): paired plot production difference (kg/ha dry matter) = $75.26 - 7.11X_1 - 0.00007X_2$.

This model did not predict paired plot production differences as well as the other alfalfa models did (Appendix H.). The smallest difference between an observed and a predicted value was 1.71 kg/ha, while the greatest difference was 120.78 kg/ha.

When paired plot production differences from the 1993 second harvest and the 1994 second harvest were each tested with the combined model, R^2 values decreased. The second 1993 harvest had an R^2=0.345 and the second 1994 harvest had R^2=0.262. Adding the 2 variables that were significant in both of the second harvests to the analyses did not increase the combined second harvest model's predictive ability for the 1993 second harvest or for the 1994 second harvest production differences between paired plots.

Field and Landscape Variables That Influenced Production Levels in Red Kidney Bean Fields

Variables that were significantly correlated with differences between red kidney bean paired plot production were mostly landscape variables (Table 34). Generally, there was less production when there was greater wooded area within evaluation areas, especially if wooded areas had highly selected natual forage species, such as aspen (Rogers et al. 1981). In the high deer density area, red kidney bean fields had less production when spring food quality was low.

Influential Red Kidney Bean Field Variables

Field size and perimeter length were not significantly correlated with paired plot production differences, nor was the percent of development edge adjacent to field perimeters. In the low deer density area during 1994, production losses were greater when the percent of bean field perimeters adjacent to wooded areas was greater ($P \leq 0.05$) (Table 34). During 1994, bean fields in the high deer density area had less production when the percent of field perimeters adjacent to wooded areas decreased.

Fields in the high deer density area had less production when hills were present in the fields. The

Table 34. Significant correlations ($P \leq 0.20$) between differences in red kidney bean paired plot production and field and landscape variables for 1993 and 1994 harvests and for combined harvests in both the high and the low deer density areas during 1993 and 1994 in northern lower Michigan.

Variable	HD93[a]	HD94[b]	LD93[c]	LD94[d]	HD[e]	LD[f]
<u>Field variables</u>						
% of field perimeter adjacent to agricultural areas				+		+
% of field perimeter adjacent to wooded areas	+	-		-		-
% block permits used	+				+	
<u>Landscape variables</u>						
road type nearest to field (ie. highway, dirt, 2-track)	*					
area (ha) of different vegetation types in evaluation area:						
agriculture	+	+			+	
openings				+		
upland hardwood						-
lowland hardwood	-	-		-		-
aspen/birch	-	-				-
pine/upland conifer		+				-
lowland conifer						+
perimeter length (m) of different vegetation types in evaluation areas:						
agriculture						+
openings				+		
lowland hardwood				-		-
aspen/birch	-					
pine/upland conifer	+				+	-

Table 34 (cont'd).

Variable	HD93	HD94	LD93	LD94	HD	LD
edge index for different vegetation types in evaluation areas:						
agriculture	-				-	
lowland hardwood				-		
aspen/birch		+				-
pine/upland conifer	+	+			+	
ratio of agriculture to different vegetation types in evaluation areas:						
agriculture to wooded (all wooded types combined)			+		+	+
agriculture to upland hardwood	-		+		-	+
agriculture to lowland hardwood	+					
agriculture to aspen/birch	+		+		+	+
agriculture to pine/upland conifer			+	-		+
HSI values:						
HSI spring food	+				+	
HSI security cover		-	+			
SI values:						
SI forest		+				
SI open				-		
SI agriculture (fall/winter)	+					
SI agriculture (spring)	+				+	

Table 34 (cont'd).

Variable	HD93	HD94	LD93	LD94	HD	LD
vegetative characteristics:						
stem density (per ha)			-			-
mean horizontal cover				+		+
mean vertical cover				-		-
distance measurements:						
distance to nearest thermal cover stand (M4V1)		+			+	
distance to nearest house, barn, or livestock			-	+		+

[a]high deer density area 1993
[b]high deer density area 1994
[c]low deer density area 1993
[d]low deer density area 1994
[e]high deer density area harvests combined
[f]low deer density area harvests combined
[+]positive Pearson's correlation coefficient ($P \leq 0.20$, Sprinthall 1990)
[-]negative Pearson's correlation coefficient ($P \leq 0.20$)
[*]significant $P \leq 0.01$ (unpaired t-test, Sprinthall 1990)

1993 harvest had 13.37 kg/ha less production and 1994's harvest had 91.57 kg/ha less production when hills were present in fields. In the low density area, fields without hills had 123.81 kg/ha less production.

Fertilizer, herbicide, and pesticide use also showed no statistically significant relationships with paired plot production differences for any of the harvests. There was not a large enough sample size to determine what, if any, effects fertilizers, herbicides, and pesticides might have on levels of deer caused crop loss in the high density area (N=20) or the low density area (N=15).

Irrigated fields had less production than fields that were not irrigated. In the high deer density area during 1993, fields that were irrigated had 208.37 kg/ha greater loss than fields that were not irrigated. There was not enough information to test 1994 data (only 1 field was irrigated). Mean paired plot production differences between irrigated fields and fields that were not irrigated in the low deer density area showed that irrigated fields had 86.18 kg/ha less production during 1993. During 1994, irrigated fields had 240.83 kg/ha less production than fields that were not irrigated.

In the high deer density area, all but 1 field was seeded with Montcalm seed during both years so it was impossible to test if seed variety affected production loss. No statistically significant production differences were found among foundation, certified, or table stock beans. In the low deer density area, 4 of the 8 fields used during 1993 were planted with light red kidney beans. Mean production losses between light red beans (Sacramento variety) and dark red beans (Montcalm variety), for both years combined, showed that fields planted with dark red kidney beans had 199.52 kg/ha less production than fields planted with light red beans.

Prodution was less in the high deer density area during 1994 as the percent of block permits used decreased (Table 34). There were no statistically significant differences among fields with no deer damage control methods, with summer shooting permits, with block permits, or with a combination of summer and block permits.

There were no statistically significant differences among general geographic field locations. In the high deer density area, the general field locations were: the Ossineke area (Alpena County), the north highway M-65 area (Alpena County), the Denton Lake area (Alpena County), the Hillman area (Montmorency County), the Hawks area (Presque Isle County), the Ocqueoc area (Presque Isle County), and the Moltke area (Presque Isle County) (Figure 4). The Ocqueoc area had the most production loss (309.3 kg/ha average, n=5), followed by the Hawks area (244.57 kg/ha average, n=7). The north highway M-65 area had a 226.35 kg/ha average production loss and ranked third during 1993 and the area also ranked third when 1993 and 1994 data were combined.

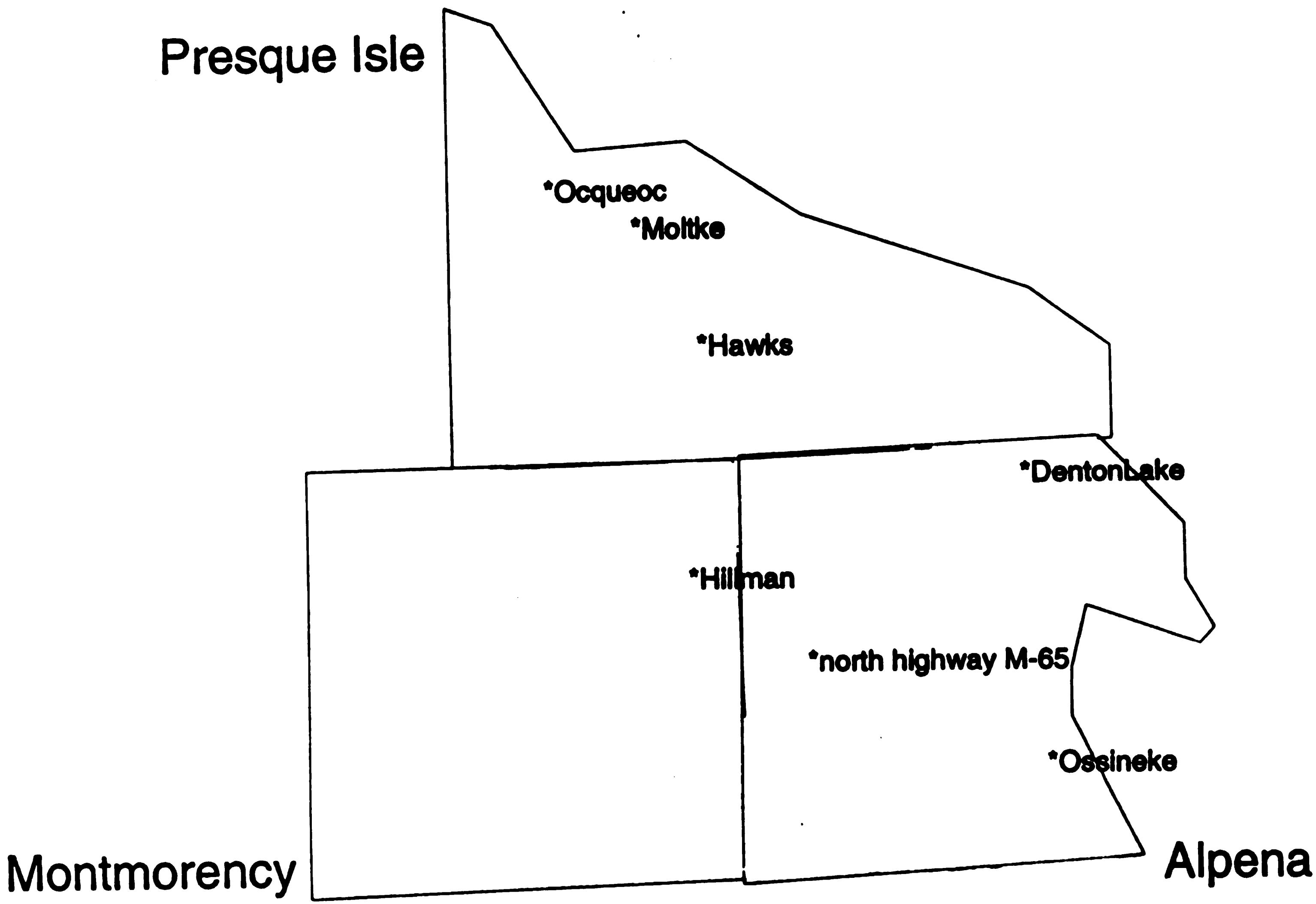

Figure 4. General geographic field locations for red kidney bean fields in the high deer density area in northern lower Michigan during 1993 and 1994.

Fields in the low deer density area were located in a much smaller geographic range (Figure 5). The order of least production loss to most production loss was: the warehouse (no loss), the Maidens Road area (no loss), the Pustinen Road area (no loss), the Johnson Road area (132.20 kg/ha loss), the 8 Mile Road area (235.30 kg/ha loss), the Marilla area (1 field, 483.1 kg/ha loss), the Yates Road area (499.05 kg/ha loss), and the Leckrone Road area (1 field, 601.1 kg/ha loss).

Influential Landscape Variables in Evaluation Areas Surrounding Red Kidney Bean Fields

During 1993 and 1994 in the high deer density area, there was less production when there were fewer agricultural hectares in evaluation areas (Table 34). Fields in 1993's harvest in the high deer density area had less production when there were greater edge diversity indices associated with agricultural areas. Perimeter lengths and edge indices for agricultural areas, and the number agricultural hectares, had no statistically significant relationships in the low deer density area.

Neither of the harvests in the high deer density area had any significant relationships between paired plot production differences and wooded (all wooded types combined) area, perimeter length of wooded areas, edge

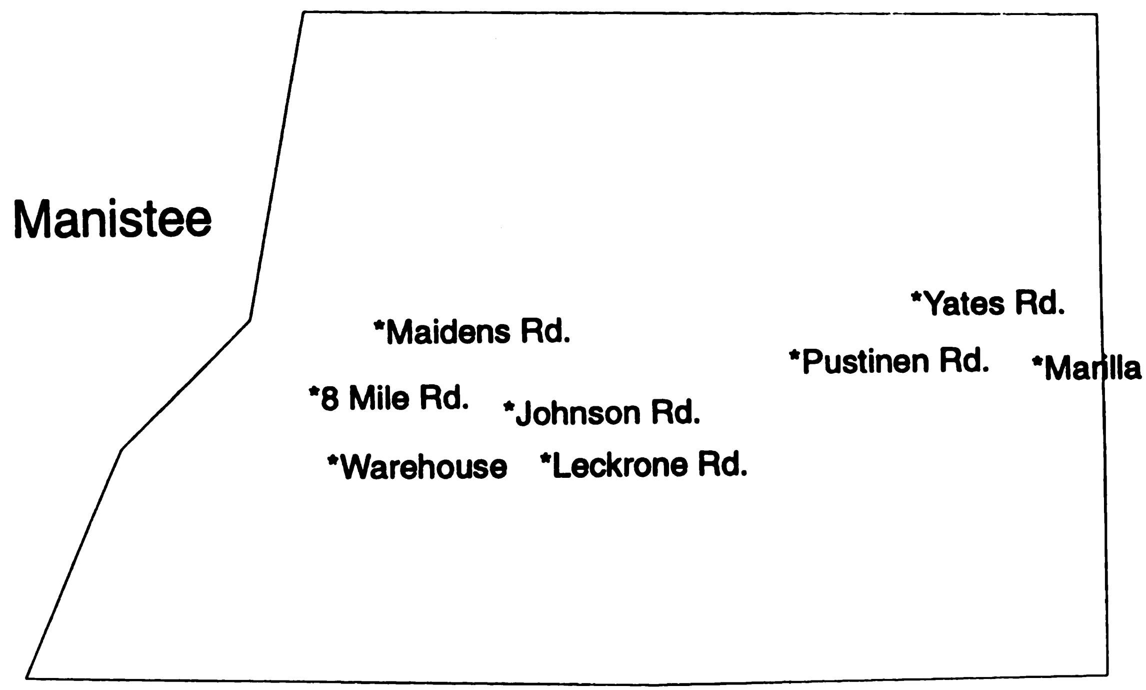

Figure 5. General geographic field locations for red kidney bean fields in the low deer density area in northern lower Michigan during 1993 and 1994.

indices associated with wooded areas, or agricultural area to wooded area ratios. In the low deer density area during 1993, there was less red kidney bean production when there was more forested area relative to agricultural area.

Production was also less in the low deer density area during 1994 when the area ($P \leq 0.008$) and perimeter length of openings was relatively less. Neither of the 2 red kidney bean harvests in the high deer density area were significantly correlated with variables associated with openings.

In the low deer density area during 1993, production was less when the area in upland hardwoods was greater relative to the area in agriculture. Red kidney bean fields in the high deer density areas had the opposite correlation during 1993; there was more production loss when there was more agricultural area relative to upland hardwood area (Table 34).

Production losses during 1993 in the high deer density area were greater when there were more hectares of lowland hardwoods in evaluation areas, and when the area of lowland hardwoods comprised a greater proportion of the evaluation area than the area of agricultural lands. The 1994 red kidney bean harvest in the low deer density area had more production loss when the area, perimeter length, and edge index of lowland hardwood stands increased (Table 34).

The 1993 red kidney bean harvest in the high deer density area had less production when the perimeter length of aspen and birch stands was greater within evaluation areas. Similarly, the 1994 bean harvest in high deer density area had less production when evaluation areas had lower edge diversity indices associated with aspen and birch stands. Fields in the 1993 high deer density area and in the 1993 low deer density area had less production when there was more aspen and birch area relative to agricultural area (Table 34).

When perimeter length and edge diversity indices were lower for pine and upland conifer stands, there was less production in fields in the high deer density area during 1993. The red kidney bean harvest in the high deer density area during 1994 had the same correlation with pine and upland conifer edge diversity indices. The 1993 bean harvest in the low deer density area had less production when there was less agricultural area relative to pine and upland conifer area within evaluation areas. The 1994 harvest showed the opposite relationship, with less crop loss when pine and upland conifer area increased relative to agricultural area (Table 34). There were no significant correlations between paired plot production differences and variables associated with lowland conifer areas for any of the harvests.

Fields in the high deer density area during 1993 had less production when there were lower HSI's for spring food ($P \leq 0.03$), fall and winter food SI's for agricultural areas, and spring food SI's for agricultural areas

($P \leq 0.05$) (Table 34). The harvest in the high deer density area during 1994 had less production when HSI's for security cover were greater and when SI's for forested areas were lower. The 1993 red kidney bean harvest in the low deer density area showed the opposite relationship with less production in fields whose evaluation areas had lower HSI's for security cover. For fields in 1994's low deer density area, production was less when the SI's for openings were greater (Table 34).

None of the vegetative characteristics showed significant correlations with paired plot production differences in the high deer density area. In the low deer density area, production was less when stem densities per hectare and mean vertical cover percentages were greater, and when there was less mean horizontal cover (Table 34).

Fields in the high deer density area had 3 variables that were significantly correlated with paired plot production differences during both years. The percent of field perimeter adjacent to wooded areas, the number of agricultural hectares, and the edge diversity index for pine and upland conifer stands. The ratio of agricultural area to pine and upland conifer area and the distance to the nearest house, barn, or livestock pasture ($P < 0.03$) significantly correlated with differences between paired plot production in the low deer density area during both years.

Influential Field and Landscape Variables for Combined Harvests in the High Deer Density Area and for Combined Harvests in the Low Deer Density Area

Data sets for the 1993 and 1994 harvests in the high deer density area and for the 1993 and 1994 harvests in the low deer density area were combined to quantify the influence of regional deer densities on crop production. Precipitation had no statistically significant influence ($P \geq 0.38$ for the high density area and fields in the low density area were too close to each other to differentiate precipitation levels) on paired plot production differences so growing conditions in each deer density area (independent of individual farmer's field management) were assumed to be not different during both years.

Three field variables were significantly correlated with differences between paired plot production when harvests were combined within each deer density. Fields in the high deer density area had less production when lower percentages of block permits were used (Table 34). The low deer density area had less production when smaller percentages of field edges were bordered by agriculture and when greater percentages of field perimeters were bordered by woodlands. When hills were present in fields in the high deer density area, the mean crop loss was 60.68 kg/ha greater than in fields that did not have hills.

Production was less in the high deer density area when less agricultural area was present ($P \leq 0.05$) and when there was more lowland hardwood and more aspen and birch area within evaluation areas (Table 34). In the low deer density area, production was less when there was greater upland hardwood area, lowland hardwood area, and pine and upland conifer area, and when there was less lowland conifer area within evaluation areas (Table 34).

Similarly, there was less production in the low deer density area when lowland hardwood and pine and upland conifer perimeter lengths were shorter. In contrast, there was less production in the high deer density area when the perimeter lengths were shorter and edge indices were lower ($P \leq 0.03$) for pine and upland conifer stands (Table 34). Fields in the high density area also had less production when edge diversity indices associated with agricultural areas were greater. Higher aspen and birch edge diversity indices correlated with less crop loss in the high deer density areas and with greater loss in the low deer density area (Table 34).

Fields in the high and the low deer density area had less production when evaluation areas had more wooded area and more aspen and birch area relative to the amount of agricultural area (Table 34). Fields in the low deer density area had less production when there was more pine and upland conifer area relative to agricultural area ($P \leq 0.05$). Proportions of agricultural area to upland hardwood area had opposite correlations between the 2 deer densities (Table 34). In the high density areas, there was less production when there was less upland hardwood area relative to agricultural area. For fields in the low density areas, production was less when evaluation areas had more upland hardwood area relative to agricultural area.

All of the correlations between HSI's and differences between paired plot production occurred with data from fields in the high deer density area. Production was less in the high deer density area when there were lower HSI's and SI's for spring food quality (Table 34). Only fields in the low density area had significant correlations between vegetative characteristics and paired plot production differences. The low deer density area had less production when stem densities and mean vertical cover were greater, and when there was less mean horizontal cover (Table 34).

Red kidney bean fields in the high deer density area had less production when the distances from fields to the nearest 2.0 ha thermal cover stand decreased. In addition, the low deer density area had less production when houses, barns, or livestock pastures were closer to fields.

Predictive Red Kidney Bean Crop Loss Models

1993 Harvest in the High Deer Density Area

The best regression model (R^2=0.833, $P \leq 0.01$) identified 3 variables (n=66) that best described paired plot production differences during the 1993 harvest (Table 35). The predictive equation was (in order of variables listed in Table 35): paired plot production difference (kg/ha) = $-264.34 + 735.69X_1 - 3.14X_2 - 37.13X_3$. There was less production when HSI's for spring food were lower, when the edge diversity indices associated with agricultural area were greater, and when there was less upland hardwood area relative to agricultural area.

Table 35. Variables that best described red kidney bean paired plot production differences in the high deer density area during 1993 in northern lower Michigan.

Variable	Correlation	Partial r^2
HSI for spring food	+	0.462
proportion of agriculture to upland hardwoods	-	0.257
edge diversity index associated with agricultural area	-	0.115

Observed and predicted differences between paired plot production are shown in Appendix I. Production losses are represented by negative numbers. The smallest difference between observed and predicted production estimates was 1.79 kg/ha. The greatest difference was 72.96 kg/ha.

1994 Harvest in the High Deer Density Area

Two variables (n= 66) were identified that best described red kidney bean paired plot production differences during 1994 (R^2=0.510, P $\leq$ 0.08). Production was less when the SI's for forested areas were lower (partial r^2=0.199) and when distances between the nearest thermal cover stand and red kidney bean fields was were less (partial r^2=0.132). The predictive equation was (in the order of variables presented above): paired plot production differences (kg/ha) = $-507.42 + 603.78X_1 + 0.49X_2$. The greatest difference between observed and predicted production differences was 120.70 kg/ha and the smallest difference was 3.74 kg/ha (Appendix I).

Combined 1993 and 1994 Harvests in the High Deer Density Area

Four variables best described paired plot production differences for red kidney bean fields in the high deer density areas during 1993 and 1994 (R^2=0.657, P $\leq$ 0.002) (Table 36). The predictive equation was (in the order variables are presented in Table 36): paired plot production difference (kg/ha) = $-772.04 - 0.190.33X_1 + 0.53X_2 + 190.33X_3 + 680.91X_4$. Production was less when spring food SI's for agricultural areas were lower, when there were fewer agricultural hectares in evaluation areas, and when the perimeter length and the edge diversity indices associated with pine and upland conifer stands were lower. The smallest difference between observed and predicted production differences was 4.79 kg/ha (Appendix I). The greatest difference was 119.63 kg/ha.

The 1993 and 1994 combined harvest model had a higher correlation with paired plot production differences than the individual 1994 harvest model, but a lower correlation than the 1993 harvest model. Production differences from the 1993 harvest had an R^2=0.708 when tested with the combined harvest model. No variables were selected as being statistically significant when the 1994 harvest data were tested with the combined harvest model.

Adding the 3 variables that had statistically

Table 36. Variables that best described red kidney bean paired plot production differences in the high deer density area during 1993 and 1994 in northern lower Michigan combined.

Variable	Correlation	Partial r^2
edge diversity index associated with pines and upland conifer areas	+	0.260
area of agriculture	+	0.253
perimeter length for pine and upland conifer stands	+	0.081
SI for agriculture during the spring	+	0.064

significant correlations (percent of field perimeter adjacent to woodlands, the area of agriculture, and the edge diversity index associated with pine and upland conifer areas) that were shared by both harvests to the combined model did not increase the R^2 value when the combined model was tested on the 1993 production estimates. When those 3 variables were added to the combined harvest model and tested on the 1994 production differences, The R^2 increased from 0.0 to 0.248.

1993 Harvest in the Low Deer Density Area

An R^2 of 0.390 ($P \leq 0.09$) was generated between paired plot production differences and the proportions of agricultural area to aspen and birch area (n=64). There was less production when there was greater aspen and birch area relative to agricultural area. The prediction equation was: paired plot production difference (kg/ha) = $-211.82 + 4.28X$. There were relatively large differences between the predicted and the observed estimates that were generated by the model (Appendix J). The smallest difference was 29.69 kg/ha and the largest difference was 432.08 kg/ha. Crop losses are represented by negative numbers.

1994 Harvest in the Low Deer Density Areas

Three variables (n=64) best described paired plot production differences for red kidney bean fields in the low deer density area (R^2=0.996, $P \leq 0.0004$) (Table 37). The prediction equation was (in order variables are listed in Table 37): paired plot production difference (kg/ha) $= 541.44 + 12.28X_1 - 3247.58X_2 - 7.20X_3$. There was less production when lower percentages of red kidney bean field perimeters were adjacent to other agricultural fields, when SI's for openings were greater, and when the mean percent of vertical cover was greater.

Compared to the 1993 harvest model, the 1994 model had predicted paired plot production differences that were closer to the observed differences (Appedix J). The greatest difference between observed and predicted values

Table 37. Variables that best described red kidney bean paired plot production differences in the low deer density area during 1994 in northern lower Michigan.

Variable	Correl-ation	Partial r^2
percent field perimeter adjacent to agriculture	+	0.848
SI for openings	-	0.135
mean vertical cover	-	0.013

was 57.56 kg/ha and the smallest difference was 0.54 kg/ha. Production losses are represented by negative numbers.

Combined 1993 and 1994 Harvests in the Low Deer Density Area

Four variables generated an R^2 of 0.717 ($P \leq 0.008$) when 1993 and 1994 harvest data were combined (Table 38). The prediction equation was (in the order variables are listed in Table 38): paired plot production difference (kg/ha) = $-1176.14 + 248.36X_1 + 487.04X_2 + 12.02X_3 + 4.29X_4$. The combined model had a higher R^2 value than the 1993 harvest model, but a lower R^2 value than the 1994 harvest model. The proportion of agricultural area to aspen and birch area was shared by both the combined harvest model and by the individual 1993 harvest model.

Production was less when there was less agricultural

Table 38. Variables that best described red kidney bean paired plot production differences in low deer density areas during 1993 and 1994 in northern lower Michigan combined.

Variable	Correlation	Partial R^2
proportion of agriculture to upland hardwoods	+	0.271
distance to houses, barns, livestock	+	0.235
mean horizontal cover	+	0.114
proportion of agriculture to aspen and birch	+	0.097

area relative to the amount of upland hardwood area and the amount of aspen and birch area. There was also less production when there was less mean horizontal cover and when houses, barns, or livestock pastures were closer to the bean fields. The predictive ability of the combined harvest model did not increase when the 2 Pearson's correlations (the ratio of pine and upland conifer area to agricultural area and the distance to houses, barns, or livestock pasture) that were significantly correlated ($P \leq 0.20$) with differences between paired plot production in both harvests were added into the combined harvest model.

Observed and predicted production differences were plotted to show the combined harvest model's predictive ability (Appendix J). The greatest difference between observed and predicted values was 252.98 kg/ha and the smallest difference was 6.0 kg/ha.

Orchard and Landscape Variables That Influenced Percentages of Browsed CAG Twigs in Evaluation Areas Surrounding Tart Cherry Orchards

None of the orchard variables (orchard variables are the same as field variables) showed statistically significant correlations with percentages of browsed CAG twigs (Table 39). All statistically significant correlations with percentages of browsed CAG twigs were related to attributes associated with vegetation types, HSI's and SI's, and distance measurements.

More browsing occurred when evaluation areas had more upland hardwood area increased and less lowland conifer and aspen and birch area. There was also more browsing when there was less agricultural area relative to open area ($P \leq 0.002$), upland hardwood area ($P \leq 0.02$), lowland hardwood area, aspen and birch area, and pine and upland conifer area ($P \leq 0.03$) (Table 39).

Browsing increased during both years as the perimeter length and the edge diversity indices associated with agricultural areas decreased. During 1993, browsing on CAG twigs increased when the perimeter length of aspen and birch stands was shorter (Table 39).

Many of the variables associated with aspen and birch area and with lowland conifer areas were significantly correlated with browsing intensity (Table 39). The average area of those wooded types was not very high and many of the

Table 39. Significant correlations ($P \leq 0.20$) between browsed current annual growth (CAG) percentages and orchard and landscape variables during 1993, 1994, and both years combined in northern lower Michigan.

Variable	1993	1994	Combined
Landscape variables			
area (ha) of different vegetation types in evaluation area:			
wooded (all wooded types combined)			+
openings			+
upland hardwood	+	+	+
aspen/birch	-	-	
pine/upland conifer			+
lowland conifer	-		-
perimeter length (m) of different vegetation types in evaluation areas:			
agriculture	-	-	-
aspen/birch	-	-	-
lowland conifer			-
edge index for different vegetation types in evaluation area:			
agriculture	-	-	-
aspen/birch	-	-	-
pine/upland conifer			-
ratio of agriculture to different vegetation types in evaluation area:			
agriculture to openings	-		
agriculture to upland hardwood	-		-
agriculture to lowland hardwood	-	-	
agriculture to aspen/birch	-	-	-

Table 39 (cont'd).

Variable	1993	1994	Combined
agriculture to pine/upland conifer	-		
agriculture to lowland conifer	-		-
HSI values:			
HSI spring food		+	+
SI values:			
SI open	+		
SI agriculture (spring)		+	+
SI for security cover with agriculture included	+		+
distance measurements:			
distance to nearest thermal cover (M4V1)	+		+

[+]positive Pearson's correlation coefficient ($P \leq 0.20$, Sprinthall 1990)
[-]negative Pearson's correlation coefficient ($P \leq 0.20$)

orchard evaluation areas had little or none of these forest types (Table 24). Therefore, some of the correlations between browsing levels and aspen and birch stands and lowland conifer stands might be a result of zeros in the data sets.

During 1994, the percentage of browsed CAG twigs was greater when there were higher HSI's for spring food and spring food for SI's for agricultural area. During 1993, browsing increased as SI's for openings ($P \leq 0.02$) and SI's for security cover with agricultural areas included cover increased (Table 39).

During 1993, the percentage of browsed CAG twigs was greater when the distance to the nearest thermal cover stand was farther away. This correlation is the opposite of distance to thermal cover correlations for alfalfa fields and red kidney bean fields in the high deer density study area (Table 39).

Influential Orchard and Landscape Variables for 1993 and 1994 Combined

Greater numbers of significant correlations between variables and browsing intensity on tart cherry CAG twigs were elicited when 1993 and 1994 data sets were merged (Table 39). Browsing intensity on CAG twigs increased as the amount of woodland area, open area, upland hardwood area

($P \leq 0.01$), and pine and upland conifer area increased, and as lowland conifer area decreased within evaluation areas (Table 39). As perimeter lengths for aspen and birch and lowland conifer stands increased, browsing intensity decreased. Similarly, browsing decreased when there were greater edge diversity indices associated with aspen and birch stands, pine and upland conifer stands, and agricultural area ($P \leq 0.03$). As agricultural area increased relative to the amount of upland hardwood area, aspen and birch area, and lowland conifer area, there was less browsing intensity on CAG twigs (Table 39).

There was more browsing on tart cherry trees when there were higher HSI's for spring food, spring food SI's for agricultural area, and SI's for security cover that included agricultural area. Similar to 1993's correlations, browse percentages were positively correlated with the distance to the nearest thermal cover stand when data from 1993 and 1994 were combined into one data set.

Predictive Model for Percentages of Browsed CAG Twigs in Tart Cherry Orchards

Predictive Model for 1993 and 1994 Combined

When 1993 and 1994 data sets of percentages of browsed CAG twigs were combined, an $R^2=0.693$ ($P \leq 0.005$) was calculated with 1 variable: the ratio of agricultural area to upland hardwood area. The predictive equation was: 18.58 - 6.92X. More browsing on tart cherry trees occurred when there was more upland hardwood area relative to agricultural area. The largest difference between observed and predicted percentages was 7.74% and the smallest difference was 0.70% (Appendix K).

The proportion of agricultural area to upland hardwood area was a relatively good predictor variable for predicting browsing intensity during an individual year. An R^2 of 0.968 was generated when 1993 browse percentages were tested with the combined model. The 1994 browse percentages had an $R^2=0.639$ when tested with the combined model. The R^2 values did not increase when 1993 and 1994 percentages of browsed CAG twigs were each tested with the combined 1993 and 1994 model. This model included the 2 variables that were significant during both years (upland hardwood area and edge diversity index for agricultural areas).

Although 1993 and 1994 data were analyzed with stepwise regression procedures, predictive models are not presented for individual years because sample sizes were small during 1993 (n=4) and 1994 (n=5) which makes the usefulness of the model output questionable. One variable was selected through stepwise procedures for each year and each of these could be shown to influence, or predict, browsing intensity on tart cherry trees if further research is done. During 1993, more browsing occurred when there was more open area relative to agricultural area. During 1994, browsing increased when agricultural areas provided higher quality spring food.

DISCUSSION

Deer incorporated agricultural fields into their foraging patterns because crops were readily available food sources from early April through October during 1993 and 1994. Habitat suitability indices and SI's indicated that agricultural lands were excellent foraging areas (Tables 21 and 22), especially during late spring through autumn when deer had to maintain energy required for giving birth, lactation, growth, and preparation for the rut (Gladfelter 1984, Murphy et al. 1985). The period of time crops were grown and were available to deer, and the accessibility of fields and crop plants to deer in northern lower Michigan, exacerbated the problem of deer eating agricultural crops.

Mixtures of woodlands and agricultural crops in landscapes (Table 24) provided alluring habitat components for deer. Habitat availability and spatial relationships of habitat components can affect where, and how far, deer move and what they eat. Describing the physical landscape in which deer live provided information about the conditions under which deer inflicted the most crop loss. Generally, production losses were best explained by combinations of variables that described characteristics of forested areas and agricultural areas (Tables 29, 30, 31, 32, 33, 35, 36,

37, and 38) and by spring food quality (Tables 29, 33, 35, and 36).

Alfalfa Fields

The amount deer used alfalfa was related to the contributions alfalfa made to deer habitat quality. Alfalfa growth characteristics, field characteristics, and spring food quality contributed to the statistically significant production differences that were found among the 3 edge categories during 1993 and 1994 (Tables 10, 11, and 12). The availability of other vegetation types within evaluation area landscapes surrounding alfalfa fields best described alfalfa paired plot production differences. Generally, fields had less production when agricultural crops provided higher quality spring food and when surrounding areas had more wooded area (especially stands with highly selected natural forage species).

Contributions Alfalfa Fields Made to Deer Habitat Quality

Alfalfa was a widely available early spring food within the high deer density study area. It initiated growth before most forest understory woody vegetation and before many forbs and grasses (Murphy et al. 1985, Austin and Urness 1993, Gould and Jenkins 1993, visual observation). Deer use of alfalfa fields increased as snow melted and as alfalfa began to grow new shoots. Peak deer counts in crop fields along highway survey routes in the high deer density study area was in March and April during 1994 (Sitar 1996). During those 2 months, 1,507 deer were counted in fields. The number of deer sighted during other months ranged from 8 to 202. Sitar's results (1996) showed that relatively large numbers of deer moved into crop fields to feed during early spring.

Openings, grasslands, hay, and alfalfa crops become important food sources for deer during spring-time and throughout summer months (Rue 1989). McCaffery et al. (1974) found that 80% by volume of rumen contents were grasses and herbaceous plants. Similarly, Nixon et al. (1991A) found that crops comprised 84% of rumens during spring and 48% during summer. Alfalfa shoots provide nutritional food for deer at a time when deer are beginning to move and increase their weight after a winter of reduced food intake and lower metabolic rates (Mautz 1978, Murphy et al. 1985). Dusek et al. (1989) states that alfalfa dominated female white-tailed deer diets between April and September along the lower Yellowstone River. Results for this study showed the overall mean weight loss in alfalfa fields ranged from 83.5-104.28 kg/ha for the first harvests during 1993 and 1994 (Table 7). These data illustrated that alfalfa fields were a relatively important food source during April, May, and early June.

Older, less vigorously growing alfalfa fields can still contribute to deer nutrition because its quantity can offset its decreased nutritional value (Hobbs and Hanley 1990). Deer may heavily forage in alfalfa fields because they can maximize the energy spent acquiring food with the energy gained from that food and also potentially increase survival for themselves and their fawns (Murphy et al. 1985, Lenarz 1987).

Optimal foraging theory, when applied to white-tailed deer, contends that deer food preferences are a result of the amount of energy needed to acquire food and the abundance of the food versus the risk involved in getting to the food (Belovsky 1985, Williamson and Hirth 1985, and Bender and Haufler, unpubl.). Williamson and Hirth (1985) reported that deer fed in the middle of clear-cuts when preferred food was abundant. Alfalfa could be a preferred white-tailed deer food, especially during spring months in northern lower Michigan. Alfalfa is also a renewable food source that grows quickly after being cut (usually during June for first harvests and during June to early September for second harvests) which makes it a highly available food source throughout July, August, September, and October. The availability and abundance of new alfalfa shoots at time when deer needed nutritional forage could explain statistically significant mean production differences along all alfalfa field edge categories during the 2 growing seasons evaluated in this study (Tables 10, 11 and 12).

Gould and Jenkins (1993) concluded that agricultural areas are key foraging and security areas during the summer. Deer might have used alfalfa fields as security cover when plant growth reached a height that would conceal a bedded deer or partially conceal a standing deer. Murphy et al. (1985) states that white-tailed deer in Wisconsin preferred grasslands for fawning areas and that deer used non-irrigated croplands in proportion to their availability during spring. Alfalfa fields, as non-irrigated cropland, can serve deer in the same capacity as grasslands providing food, cover, and bedding areas. Alfalfa fields may be attractive to adults and to fawns because, in addition to providing food and cover, fields warm up quickly in the morning, they are relatively biting insect free (Beier and McCullough 1990), and there is usually a relatively open view of any approaching danger.

Habitat suitability indices and SI's reflected that alfalfa was an important early spring food source and that some alfalfa fields provided security cover (Tables 21 and 22). Evaluation areas surrounding alfalfa fields had the greatest mean HSI's for spring food and for fall and winter food and the greatest mean fall and winter food SI for agricultural areas. Areas around alfalfa fields also had the second highest mean spring food SI for agricultural areas (Table 22). The second 1994 harvest had more crop loss when HSI's for spring food were higher, suggesting that deer concentrated their feeding in areas that provided greater quality fall, winter, and spring food. During early spring, alfalfa fields might be serving the same function as natural openings or grasslands by providing an abundance of forage (Table 22).

The 1993 first harvest model (Table 29) demonstrated that alfalfa fields were essentially high quality openings. Evaluation areas around alfalfa fields had relatively few hectares of openings (86.38 ha average) (Table 24). Openings also had a mean SI of 0.20 which is relatively low on the 1.0 SI scale (Table 22). There was less production when the spring food quality of openings was lower, the perimeter length associated with open areas was shorter, and the SI's for agriculture during the spring were higher. These results suggest that deer used alfalfa fields more when there was less natural herbaceous food available and when food quality of agricultural areas was relatively high. The presence of poorer quality herbaceous openings could have created increased deer pressure in alfalfa fields during early spring, especially before other crop types were planted and natural woody vegetation leafed out.

During the growth period for the second harvests, alfalfa fields continued to provide relatively high quality forage as well as bedding areas for fawns and adult deer. The second harvest of 1993 and 1994 had significant production loss (Table 7) indicating that deer continued to feed in alfalfa fields throughout the summer and into September. Another indication of deer use of alfalfa fields during the time the second harvest was growing was the number of deer beds seen in fields. A total of 87 beds (average 2.81 beds per field) were counted during the first harvest, while a total of 212 beds (average = 6.42 beds per field) were counted during the second harvest.

Patterns of Production Loss in Relation to Alfalfa Field Characteristics

Some of the field variables demonstrated trends with crop production levels. Field size, field perimeter length, the percent of perimeter adjacent to wooded areas, presence of hills, field location, number of deer beds seen in fields, and fertilizer use varied with production in at least 1 harvest, but the correlations between these variables and production levels were not consistent between the first and second harvests during both years (Table 28). Of the field variables, only field perimeter length was selected as a significant predictor variable (Table 29).

During the second harvests, larger fields had less production, although alfalfa fields in this study were relatively small (8.71 ha) compared to red kidney bean fields. The relatively small average field size, combined with the nutritional value of alfalfa and the potential for alfalfa to provide security cover, might make entire fields usable to deer, not just areas adjacent to wooded cover. Murphy et al. (1985) concluded that areas that provide both food and cover are heavily used by deer while areas of habitat that provide only food are used nearer to cover. This conclusion is further supported by Flyger and Thoerig (1962) who reported that corn provided security cover during its later growth stages and deer, therefore, did not restrict their feeding near wooded areas. The conclusions of other researchers were supported by this study because many production loss ranges associated with the 3 edge categories and the core areas overlapped with each other (Tables 7, 10, 11, and 12), suggesting that deer foraged in all areas of alfalfa fields during the time the first and the second harvests were maturing.

Relatively small alfalfa field size (8.71 ha average size) and the potential cover provided by alfalfa fields could explain statistically significant production losses along agriculture and development edge categories (Tables 10 and 12). Since alfalfa fields provided early spring forage, deer might have been willing to feed farther away from security cover, especially before forage was available in forested areas. Production losses along development edges could have occurred because fields were relatively small enough that security cover was never too far away or because relatively rural development did not influence deer feeding patterns in alfalfa fields.

Although feeding occurred along all edge categories, relatively less production could have occurred along wooded edges (Table 11) because deer concentrated their foraging activities more heavily along those edges. It is possible that production losses were significant near wooded areas during the first and the second 1994 harvests because wooded perimeters provided potential security cover near which deer restricted most of their foraging activity. The mean stem density for areas surrounding alfalfa fields was 35,352 stems per hectare which received an SI of 1.0 (Bender and Haufler, unpubl.) and security cover HSI's averaged 0.70 in evaluation areas around alfalfa fields (Table 21). These results indicated that relatively high quality security cover was available near alfalfa fields, especially after late May when leaves emerged in forested areas.

Field perimeter length showed both positive and negative correlations with paired plot production differences for the first and the second harvests, respectively (Table 28), and field perimeter length was chosen as a predictor variable for 1993's first harvest model (Table 29). These correlations with production differences also could have been related to field size and security cover requirements. For the predictive model for the first harvest during 1993, shorter perimeter lengths could have been indicative of smaller fields. In smaller fields, distances to security cover would have been shorter and this might have made entire fields and their perimeters available to foraging. This conclusion is further supported by the results of the combined 1993 and 1994 first harvest data; there was less production when field perimeters were bordered by a greater percentage of woodlands and a lower percentage of agriculture (Table 28).

Since alfalfa fields had the highest percentage of field edge bordered by woodlands (Appendix E), it is possible that larger fields (which also correlated with greater crop loss during the 1993 second harvest and the combined 1993 and 1994 second harvests) had more field perimeter length adjacent to woodlands. There was less cover available before leaves come out in forested areas during April and May than there was during June through September. There could have been less production for second harvests in fields that had longer perimeters (Table 28) because those perimeters were adjacent to higher quality security cover once natural vegetation began growing. Longer sections of field perimeters bordered by wooded areas could have provided more foraging area near potential security cover and, therefore, influenced crop losses.

Statistically significant production losses were detected along agriculture edges during 1993 and 1994 (Table 10). Deer might have concentrated their feeding near multiple crop food sources at this time of the growing season. Red kidney beans and corn were 2 dominant crops in the high deer density study area and they began growing above ground shortly after most landowners took the first harvest from alfalfa fields. Both red kidney beans and corn are relatively succulent and nutritious crops (Ozoga 1994) that provide additional summer food for deer. The presence of additional crops around alfalfa fields could have caused increased deer foraging pressure in alfalfa fields as other crops perhaps attracted higher numbers of deer or as deer traveled through, and bedded in, alfalfa fields. Corn also provides potential security cover during its later growth stages (Flyger and Thoerig 1962). Security cover provided by adjacent corn fields could have increased the amount of crop loss along alfalfa field perimeters if deer concentrated their foraging near areas that provided security cover.

No statistically significant production losses were detected in core areas (Table 9). Although feeding concentrated along field edges, production loss in core areas ranged from 64-110 kg/ha which is close to some of the production losses documented along the 3 edge categories (losses along agriculture edges ranged between 52 kg/ha and 131.91 kg/ha, wooded 71.99-215.03 kg/ha, and development 59.33-249.05 kg/ha). It is possible that statistically significant production losses were not detected in core areas because 2 exclosures were not enough exclosures for detecting statistically significant losses.

Other field variables showed trends for contributing to production losses (Table 28). In fields that had hills, there was a 64.26 kg/ha greater loss during the combined 1993 and 1994 harvests, and a 233.65 kg/ha greater loss during 1993's first harvest than fields without hills. These results could be attributed to hills providing some degree of security cover, depending on hill size and slope. Cover provided by hills could have been especially important during the time the first harvests grew because leaves in forested areas did not grow until late May.

In fertilized fields, alfalfa probably grew better and was more nutritious which could have led to greater deer foraging pressure in those fields. This is supported by the 59.99 kg/ha to 133.96 kg/ha range of less production in fields that had fertilizer applied than in fields that were not fertilized. Production levels for the first harvests during 1994 and for the combined 1993 and 1994 first harvests correlated with the number of deer beds seen in alfalfa fields (Table 28). Based on this correlation, the number of deer beds observed in an alfalfa field could be used as an indication of the intensity deer are using a particular alfalfa field.

The number of deer sighted in alfalfa fields was 1 of 2 predictor variables for the 1993 and 1994 combined second harvest model. Methods of counting deer were not standardized. The number of deer seen was noted during daytime hours only, not at dawn, dusk, or during the night. More standardized survey techniques might increase the value of this predictor variable. Numbers of sighted deer, coupled with the number of deer beds observed in fields, could be valuable indicators of the relative intensities at which deer are using alfalfa fields.

There were no statistically significant relationships between precipitation levels and alfalfa production ($P \geq 0.88$). When production levels were plotted against precipitation levels during 1993's second harvest, there was a slight trend of less production when there was less precipitation (Appendix F).

The percentage of block permits used by landowners was a predictor variable for the combined 1993 and 1994 first harvests model (Table 31). Potentially high deer densities in areas around fields for which permits were issued could have accounted for the correlation between production losses when a greater percentage of permits were used. These results might be attributed to the possibility that it could take a few years to reduce deer numbers to a point where crop loss would show a measurable decrease. It is also possible that non-depredating deer were the ones that were shot as they moved between their summer and winter ranges.

Alfalfa Predictive Models and Landscape Characteristics Surrounding Alfalfa Fields

Stepwise regression model output showed relatively high R^2 values for 3 of the 4 harvests, but for combined harvests the R^2 values decreased to below 0.70. Production losses were generally best predicted from data associated with each harvest (Tables 29, 30, 32, and 33). Since annual data collection is not feasible for wildlife managers or for farmers, combined harvest predictive models might be the most useful way to predict levels of production loss (Table 31 and the model for the 1993 and 1994 second alfalfa harvests combined). Individual harvest models and significant correlations can be used as expanded references for additional factors that influenced deer crop use.

The contributions of variables that had significant Pearson's correlation relationships with production levels in 1993 and 1994 first harvests and in 1993 and 1994 second harvests is debatable (Table 28). The correlations that were shared by both first harvests and by both second harvests had mixed results for increasing the predictive ability of models. Generally, the shared variables that were selected into models during stepwise procedures increased the predictive ability of the individual first harvest models but did nothing for the second harvest models. The 2 variables that increased the R^2 value for the first 1994 harvest could be used in combination with combined model variables to predict production levels for subsequent growing seasons.

Predictor variables illustrated that crop losses were most influenced by surrounding habitat quality (Tables 29, 30, 31, 32, and 33). General trends elicited by Pearson's correlation coefficients were that less production occurred when greater amounts of wooded areas were available and when agricultural areas provided higher quality spring food (Table 28). On a more specific level, production was less during the first harvests when stands that provided thermal cover were relatively close to fields (the average distance from fields to thermal cover was 302.0 m, SE=44.0) and when evaluation areas had stands that contained highly preferred woody browse species (Tables 28, 29, 30, 31). The following discussion is based on the predictor variables that were selected for the alfalfa crop loss models. Many of the Pearson's correlation coefficients are also discussed because many of the relationships between variables and production levels changed when they were selected into predictive models.

The model for 1994's first harvest and the model for the 1993 and 1994 combined first harvests had correlations that suggested interrelationships among variables associated with agricultural areas and wooded areas (Tables 30 and 31). The proportion of agricultural area to wooded area variable in the combined first harvest model had the opposite correlation direction than the Pearson's correlation. This most likely resulted from the related influence of agricultural and wooded variables.

Evaluation areas around alfalfa fields had an average proportion of 0.65 for agricultural area to wooded area. There were more hectares of woodlands than of agricultural lands in 34 out of the 36 evaluation areas around alfalfa fields. Individual Pearson's correlations indicated that greater production losses occurred when evaluation areas surrounding alfalfa fields had less agricultural area and more wooded area (Table 28). Predictive model correlations showed the same relationships for those 2 variables (Tables 30 and 31). In the predictive models for 1994's first harvest and for the 1993 and 1994 combined first harvest, the proportion of agricultural area to wooded area variable switched from a positive Pearson's correlation to a negative regression correlation. In the models, the correlation of the proportion variable could have been driven by interactions with the individual wooded and agricultural area variables. The models showed that fields surrounded by less wooded area and more agricultural area had less production.

Evaluation areas around alfalfa fields had more agricultural area than areas around red kidney bean fields and around tart cherry orchards (Table 24). Correlations between paired plot production differences and variables associated with agricultural areas are related to the high quality forage provided by alfalfa fields during early spring. Relatively high deer densities, coupled with greater areas of agriculture, could have led to relatively high foraging pressure on alfalfa crops. Deer foraging pressure could have been greater during first harvests than during second harvests because natural forage in forested areas did not grow until the latter part of the first harvests' growing period. Losses could have been further intensified in evaluation areas that had less agricultural area as high numbers of deer exerted more foraging pressure on whatever alfalfa was available.

Relatively less production correlated with more hectares of agricultural land during 1993's second harvest (Table 28). This could be attributed to other crop types being planted during the time the second harvest was growing. As there was relatively more crops available, deer pressure on alfalfa fields could have continued to be high as deer used alfalfa fields for cover and forage.

All of the predictive alfalfa crop loss models indicated that variables associated with forested areas were important in predicting crop loss levels (Tables 29, 30, 31, 32, 33, and the 1993 and 1994 second harvests combined model). Compared to the other 2 crop types, evaluation areas around alfalfa fields had the lowest average amount of wooded area (675.68 ha) in evaluation areas. Still, there was more woodland area than agricultural area in evaluation areas surrounding alfalfa fields (Table 24). Evaluation areas with relatively more wooded area could have supported higher numbers of deer that put foraging pressure on nearby alfalfa fields.

When wooded areas were specified to species groups, some trends were evident. Pearson's correlations for both of the individual first harvests showed that potential thermal cover area varied with alfalfa loss (Tables 28). More pine, upland conifer, and lowland conifer area present in evaluation areas meant those areas could have supported higher deer numbers throughout the winter (Nixon 1988). Deer probably filtered out of thermal cover areas when snow melted and moved their feeding activity into nearby alfalfa fields, as the model for the first harvest during 1994 indicated (Table 30).

Relationships between production levels and lowland conifer and pine and upland conifer areas changed when they became related to other variables in the predictive crop loss models. The 1994 first harvest model suggested that when evaluation areas had relatively less agricultural area, but greater agricultural area relative to lowland conifer area, there was less alfalfa production. The intensity at which deer used alfalfa fields could have been concentrated in evaluation areas that had relatively less agricultural land. In areas with relatively less agricultural area, proportionally more agricultural land in relation to lowland conifer area could have provided more abundant spring food that attracted more deer. This could have led to less alfalfa production as deer moved from winter yarding areas to areas that provided higher quality spring food.

For example, higher alfalfa losses correlated with higher spring food SI's for agricultural areas in 1993's first harvest model (Table 29). Similarly, evaluation areas with higher preference forage in woodland areas could have attracted more deer. Both of the individual first harvest models (Tables 29 and 30) had less production when edge diversity indices associated with lowland hardwood stands were higher. Areas with higher quality agricultural forage could have been associated with higher deer densities as deer searched for nutritional food after the winter months.

The second 1993 harvest model indicated there was less production when there was less lowland conifer area in relation to agricultural area. During the growing period of the second harvests (about mid-June through August), winter thermal cover was no longer a physiological requirement for deer. Less lowland conifer area could indicate that evaluation areas had relatively more wooded area that had preferred natural forage species. This could have attracted higher deer numbers that then fed in nearby alfalfa fields.

Sitar (1996) found that aspen and birch stands in the high deer density study area during 1994 had the greatest percentage of deer locations and that agriculture had the second highest percentage. Evaluation areas around alfalfa fields ranked in the top 2 (out of all 4 crop types) for the greatest mean number hectares and edge diversity index associated with aspen and birch areas (Tables 24 and 26). Evaluation areas around alfalfa fields also had the greatest mean area of agriculture. It is possible that aspen and birch areas were used in proportion to availability, but other studies suggest that deer select for aspen and birch browse and forage. Mautz (1978), Blouch (1984), Rogers et al. (1981), and Ozoga et al. (1994) state that aspen is a highly preferred deer food.

A possibility for relationships between production levels during the first harvests and forested areas that contained preferred natural forage species (Tables 28, 30, and 32) is that alfalfa fields were used heavily before forested areas grew leaves and became a major food source. Coblentz (1970) stated that crop use is related to the availability of other food types. Correlations between crop losses and areas of aspen and birch in both 1993's second harvest model and the combined second harvest model support the hypothesis that areas with highly preferred natural forage species could have attracted, or supported, higher deer numbers.

Deer numbers could have been higher in evaluation areas with more wooded area. Concentrated deer densities in forested areas could have led to greater pressure on nearby alfalfa fields. Production losses correlated with greater area of both upland hardwoods and aspen and birch and also with greater edge diversity indices associated with lowland hardwood stands (Tables 28, 30, 31, 32, and 33). If upland hardwood stands were relatively mature, there could have been less understory to provide forage. This could have led to increased pressure on alfalfa fields as deer compensated for a possible lack of food in forested areas (Taylor 1956).

A problem associated with determining the relationship between production loss and the forested categories

(Appendix C) that contain highly preferred forage species was the age of the cover maps in the MIRIS system. The coverages for this project were generated from 1977 air photos and there are no stand ages attached to the MIRIS codes. Stand age might be useful to indicate potential forage availability. For this study, the best estimation of forage availability in forested areas came from stem density, basal area, and vegetative cover measurements. Mean horizontal cover measurements suggested that vegetative cover surrounding fields was relatively high. The 0-0.5 m strata averaged 73% cover, the 0.5-1.0 m strata had a 52% average, the 2 upper strata averaged 41-47%. Stem densities in evaluation areas around alfalfa fields averaged 35,352 stems per hectare (Table 23). Also, from visual observation, it was apparent that many upland hardwood stands had some degree of available browse from regenerating maple within reach of deer.

Overall, areas around alfalfa fields had a variety of different vegetation types. Does could have selected a mix of vegetation types during May and June as they established fawning and parturition ranges. Nixon et al. (1991B) reported that does in agricultural regions of Illinois used successional forests more than expected during May and June, and used mixed forest types more than expected during post-fawning periods. Harlow (1984) determined that the best white-tailed deer habitat was comprised of a variety of different types that provided palatable, nutritious, and available food. The varieties and number of hectares of different vegetation types surrounding alfalfa fields (Table 24) and model predictor variables (Tables 29, 30, 31, 32, and 33) indicated that such variety is readily available in the high deer density study area and, therefore, might be influencing alfalfa production losses.

Red Kidney Bean Fields

Deer use of red kidney bean fields was related to the spring food quality of red kidney beans, security cover adjacent to fields, and the amount of agricultural and wooded land within evaluation areas. Generally, production tended to be less when there was less agricultural area surrounding bean fields and when there was more wooded area that had stands of preferred natural forage species. In the high deer density area, there was less production in fields that were bordered by woodlands.

Production loss for all fields combined in each red kidney bean harvest (1993 and 1994) gave an indication of losses on regional scales. As with alfalfa fields, the wide range of production losses in individual fields suggest there were ecological variables influencing levels of crop loss.

The relatively large standard errors associated with production estimates demonstrated that plant growth and yields within and among fields were highly variable (Tables 13, 15, 16, 17, and 18). Many of the production estimates generated during this study were relatively high compared to farmers' production estimates. Differences may have been a result of high within field yield variability and of landowner estimates being rough estimates for an entire field or number of fields.

Contributions Red Kidney Bean Fields Made to Deer Habitat Quality

Compared to alfalfa and tart cherries, red kidney beans contributed relatively little to deer habitat quality during fall, winter, and spring months (Tables 21 and 22). During the summer, however, red kidney beans could be a food source comparable to alfalfa and tart cherries for providing a palatable and nutritious food source. Nixon et al. (1991A) reports that deer in Illinois ate soybeans from the time of germination until late-August.

Red kidney bean fields had the lowest fall and winter food SI's for agricultural areas and the lowest spring food SI's for agricultural areas (Table 22) because the fields were plowed during the fall. There was some degree of crop residue after bean harvest, and some of the dropped beans germinated, but the beans and plants did not persist through winter and, therefore, provided no benefit to deer during those months. Some of the relatively high means for the spring food and fall and winter food HSI's for evaluation areas around red kidney bean fields were a result of surrounding alfalfa and tart cherry crops that persisted during winter months and provided food during springtime (Table 21).

Spring food HSI and SI variables were selected as predictor variables for the 1993 harvest model and for the combined harvest model in the high density area (Tables 35 and 36). There was less production when spring food quality was lower. This was the opposite trend as shown in some of the alfalfa models. This difference can be attributed to crop growth characteristics and to surrounding habitat availability. Areas around bean fields in the high deer density area had the least area of openings (Table 24) and the most agricultural area relative to area of openings (Table 25). It is possible that natural food availability was relatively low during the spring. If areas around red kidney bean fields had moderate to low quality spring food available to deer then deer might have used bean fields with greater intensity once bean plants began to grow during June. Bean fields could have compensated for relatively less forage provided by relatively few hectares of openings. Another explanation might be that young does that are pushed to more marginal habitat might be establishing parturition ranges with greater open area (Nixon et al. 1991B) and using bean fields as an additional and higher quality food source.

The low deer density area had the most area of openings, over twice as much as the high deer density area (Table 24), and the 1994 individual harvest model for the low deer density areas showed that there was less production when the quality of food (and its accessibility) in openings was greater (Table 22). Herbaceous productivity in openings might have drawn in deer during the spring and created greater deer pressure on red kidney bean fields during June.

Red kidney bean plants did not provide security cover to the degree that alfalfa or tart cherry trees did. Plants in some of the fields grew as tall as 0.75 m while others grew only 7-10 cm. Taller plants could have provided some cover but the spacing between planted rows and the relatively low growth height made it marginal cover. No deer beds or bedded deer were noted in any red kidney bean fields. Patterns of statistically significant production loss support Murphy's et al. (1985) conclusion that habitat types that provide food and not cover (or very minimal cover) are used nearer to cover.

Patterns of Production Loss in Relation to Red Kidney Bean Field Characteristics

In addition to crop nutritional qualities and availability, the amount of deer caused crop damage has been partially attributed to the presence of wooded areas surrounding fields. More crop loss has been found along field edges bordered by woodlands than along edges that had no adjacent wooded cover (deCalesta and Schwendeman 1978, Crawford 1984, Garrison and Lewis 1987).

Statistically significant production loss patterns found in this study support other studies that found greater loss nearer to wooded cover. Crop loss patterns in red kidney bean fields were more distinct with respect to edge categories than they were in alfalfa fields. All statistically significant production losses were associated with wooded edges (Table 17), with the exception of fields in the high deer density areas during 1994 that had statistically significant crop loss along development perimeters (Table 18).

There are also differing conclusions about the relationships among production loss levels and field sizes and shapes. Some studies have shown that the more field perimeter that is bordered by woodlands, the greater the loss, with the least amount of damage occurring in large, square fields where the total area is a greater proportion than the perimeter (Flyger and Thoerig 1962, Prior 1983). Other research, however, has shown that there is an inconsistent relationship between field sizes and amounts of damage. Any fields that are bordered by adequate hiding cover are susceptible to deer damage, with the intensity of damage depending on a field's shape, location, and percent of wooded edge area to crop area (deCalesta and Schwendeman

1978, Crawford 1984).

Correlation and regression results for this study did not show that field size or perimeter length influenced crop loss intenstiy (Tables 34, 35, 36, 37, 38). Although field size may not have shown relationships with production levels in correlation or regression analyses, field size could have compounded production loss patterns because of relative distances to potential wooded security cover.

The average red kidney bean field was 18.65 ha compared to 8.71 ha for alfalfa fields. Distances across fields (and therefore distances among different edge categories) were farther in red kidney bean fields than in alfalfa fields. Deer have been more reluctant to concentrate their feeding in areas of red kidney bean fields that were relatively far from forested security cover. This was further supported by Pearson's correlations with paired plot production differences and by the predictive crop loss model for the low deer density area during 1994. Relationships between paired plot production differences and the percent of field perimeter adjacent to agriculture and to wooded areas indicated that less adjacent agricultural area and more adjacent wooded area related to greater production losses (Tables 34 and 37).

Core areas and areas along agricultural edges had no statistically significant production differences (Tables 15 and 16). Although core areas and both agriculture and development edges had wide ranges of production loss (none statistically significant), the presence of adjacent wooded cover determined where deer concentrated the majority of their feeding.

Statistically significant production losses along development edges during 1994 in the high deer density area (Table 18) could have also resulted from the fact that all of those edges were directly adjacent to wooded edges. It could also be that relatively rural development does not deter deer from foraging near development areas in red kidney bean fields.

As with alfalfa fields during the first harvest of 1993 and the combined first harvests, red kidney bean fields in the high deer density area had greater crop loss when hills provided some degree of cover in fields. Irrigated fields tended to have greater production loss than non-irrigated fields. It is likely that irrigation increased bean plant succulence and growth and made plants more palatable to deer. Irrigation practices might mask possible effects precipitation levels have on bean production.

General geographic field location showed that the Hawks and the Ocqueoc areas had some consistency in comparative production loss levels. Information from radio collared deer in the high density area provide more specific information about local deer densities (Sitar 1996). One possible explanation is that the fields in the Ocqueoc area had large areas of Mackinaw State Forest land nearby (or adjacent to the field) which could have held relatively high deer densities.

Red Kidney Bean Predictive Models and Landscape Characteristics Surrounding Red Kidney Bean Fields

As with alfalfa, red kidney bean production losses were best predicted by landscape variables. Production levels were best described by variables associated with spring food quality and the amount of wooded area and agricultural area withing evaluation areas (Tables 35, 36, 37, and 38). Predictor variables also reflected deer habitat quality and availability.

The combined harvest model (1993 and 1994 harvests combined) for the high deer density area had an R^2=0.657 making it a better predictor model than the 1994 harvest model, but a less reliable model than the 1993 harvest model. The combined harvest model for the low density area had an R^2=0.717 which fell between the predictive ability of the 1993 and 1994 individual harvest models. Since it may not be feasible for wildlife managers to quantify production loss every year, the combined harvest models for the high and the low deer density areas can be used to predict different magnitudes of potential production loss.

Adding variables that were significantly correlated with paired plot production differences that were shared by 1993 and 1994 harvests within each deer density area did not significantly increase the predictive ability of either the low density combined harvest model or the high density combined harvest model. Although correlations that were significant during both years increased the R^2 for the 1994 harvest model for the high density area, the model still had poor predictive ability. Because these correlations did not increase predictive abilities of combined harvest models, those variables should not be included in the combined harvest model for either of the deer density areas.

Production losses in the high deer density area increased as edge indices associated with agricultural areas increased (Tables 34 and 35). More edge relative to interior crop area could have provided greater edge area, and more ideal habitat, for deer to concentrate their feeding. These fields also had less production when there was less agricultural area; this is similar to alfalfa fields where less production occurred when there was less agricultural area relative to wooded area. Deer could have exerted relatively high feeding pressure on whatever agriculture was available.

The combined harvest model for the high deer density area had the edge diversity index and the perimeter length associated with pine and upland conifer stands as predictor variables (Tables 36). It is possible that less pine and upland conifer edge within evaluation areas was indicative of less pine and upland conifer area. Less pine and upland conifer area could indicate that evaluation areas had greater area of more preferred forage species, such as aspen and birch and lowland hardwoods. Bean fields in the high deer density area had greater mean area, perimeter, and edge diversity index associated with aspen and birch stands (Tables 24, 25, and 26). As pine and upland conifer edge decreased, aspen and birch area and edge could have increased. Greater numbers of hectares with more highly preferred food could have supported higher numbers of deer that caused greater foraging pressure, and less production, in bean fields.

Forage availability or quality could explain less production in bean fields when distances between fields and thermal cover areas were less in the 1994 predictive crop loss model for the high deer density area. Evaluation areas around red kidney bean fields in the high deer density area had the greatest mean lowland conifer area, perimeter length, and edge diversity index (Tables 24, 26, and 27). Relatively more lowland conifer area could have supported relatively greater deer densities over the winter. Also, forage availability might have been low in conifer areas where soil quality is generally relatively poor. Deer could have had less natural forage available during winter months, become nutritionally stressed, and then put increased pressure on bean fields once the plants germinated. Conifer areas also provided relatively dense hiding cover near fields which could have contributed to losses along wooded edges.

Production losses in the fields in the low deer density area had correlations with upland hardwood areas and with aspen and birch areas that were similar to those of alfalfa fields (1993 predictive crop loss model for the low deer density areas and Table 38). Crop losses increased in bean fields when evaluation areas had more upland hardwood area and aspen and birch area relative to agricultural area. Forage and cover in upland hardwood stands could have supported high numbers of deer that used, or selected, croplands as food within their home ranges.

Compounding the possibility of higher deer numbers in upland hardwood areas in the low deer density area was the relatively low amount of area with preferred woodland forage species. Bean fields in the low deer density area had much less aspen and birch area, a 5.34 ha average compared to 228.85 ha average in the high deer density area (Table 24). The low density area also had less lowland hardwood area than the high deer density area had (Table 24). These results could indicate that bean fields were a more available food source than other natural forage species and, therefore, received relatively high deer foraging pressure.

The 1993 harvest model for the high deer density area had the opposite correlation with proportion of agricultural area to upland hardwood area than bean fields in the low deer density area (Table 35). Less upland hardwood area could have been offset by more agricultural area (Table 24) that compensated for any possible lack of natural forage in hardwood areas.

Relatively high cover percentages and stem densities indicated that food availability was relatively high (Table 23). Cover variables were correlated with production levels in the low deer density area for the combined harvest model and for the 1994 individual harvest model (Tables 37 and 38). Relatively less production with greater mean vertical cover could have been related to food availability in forested areas. Greater vertical cover could decrease food availability within deer reach by reducing the amount of photosynthesis and growth in understory plants (Crawford 1984).

Correlations between production levels and horizontal cover measurements also could have been related to less natural food availability. Most fields in the low deer density area for which vegetation sampling was done were surrounded by mature beech and maple. Many of these areas had little understory which resulted in less horizontal cover (Table 23), indicating there was less natural food within 2.0 m. As a result, bean fields could have been used more intensely to compensate for a possible lack of natural foods within deer foraging height (Taylor 1956).

The correlation between crop losses and the SI's for forested areas in the high deer density area also could be related to forage availability (1994 harvest model for high deer density areas). Foraging behavior depends on the amount and types of available food (Coblentz 1970, Dusek et al. 1989). The SI's for forested areas were a component of the fall and winter food HSI equation and was based on stems that were $\geq$ 1.50 m tall. From stems per hectare calculations, stems $\geq$ 1.50 m averaged 38% in areas around red kidney bean fields in the high deer density area. This could indicate a relative lack of natural browse availability above snow. Deer could have used red kidney bean fields more intensely to compensate for possible lower forest forage quality or availability throughout the winter.

Dusek et al. (1989) stated that forage use is influenced by local land-use practices and that areas with relatively high human activity influence times during which deer will use non-forested areas. The correlation between production levels and the distance to the nearest house, barn, or livestock pasture in the low deer density area during 1993 supported this conclusion, but the correlations in the 1994 harvest (Table 34) and the combined harvest model (Table 38) did not. The combined harvest model for the low deer density area indicated less production occurred when potential disturbances were closer to fields (Table 38).

The positive correlation between production levels and distance to houses, barns, and livestock pastures in the combined harvest model for the low deer density area could have resulted from the stronger correlation coefficient the 1994 harvest had with this variable (0.80, $P \leq 0.04$ compared to 1993's correlation coefficient of -0.55, $P \leq 0.16$).

Bean fields in 1994 had a greater mean distance to houses, barns, and livestock pastures (513 m average) than fields used during 1993 (308 m average). Less production when areas of human activity were closer to bean fields could have occurred because distances to these human activity areas were far away enough that deer were not disturbed (if such activity does disturb deer). If deer were disturbed by human activity in these areas, it is possible that they concentrated their feeding in fields used during 1994 during nighttime hours when there were fewer disturbances than during daylight hours.

Red Kidney Bean Production Loss in Relation to Deer Density

Relatively low deer densities appeared to have had effects on regional levels of production loss. The overall estimated mean red kidney bean production loss in the high deer density area was 205.63 kg/ha and loss averaged 118.54 kg/ha for the low deer density area (Table 13). Although percentages of production loss and the overall weight loss were lower in the low deer density area, many fields had weight losses similar to those in the high deer density area. Relatively little overall production loss was detected in the low deer density area because other fields compensated for those fields (Tables 15, 16, 17, and 18).

Crop losses observed along wooded edges were similar for both of the deer density areas. The overall mean loss along wooded edge categories in the low density area averaged 337.15 kg/ha loss, while the high deer density area had 282.51 kg/ha loss (Table 17). Although percentages of loss were greater in the high density area, there was greater weight loss in the low density area. Similar weight losses along wooded edges in both deer densities illustrated that deer pressure adjacent to wooded cover was comparable.

Agriculture and development edge categories in the high density area had relatively less production than the low deer density area (Tables 16 and 18), although none of the differences were statistically significant ($P > 0.10$). Greater weight losses could have resulted from greater numbers of deer that caused greater deer pressure along all 3 of the edge categories.

More deer may not necessarily mean more crop loss. Severe damage can result from a few deer that are habituated to a crop (Crawford 1984,) and concentrate their feeding in a local area (Halls 1984, Vecellio et al. 1994). Foraging localities might be learned through generations and traditions of use developed in specific sites (Marchinton and Hirth 1984, Nixon et al. 1988).

Although percentages of production loss were greater in the high deer density area, many of the fields in the low deer density study sites had noticeable areas of severely eaten plants and many of the fields had relatively high overall average losses when compared to losses in fields in the high deer density area. Deer in the low density area could have had established foraging routes and had high site fidelity for foraging areas around fields that received high deer pressure. This could partly explain the patchiness of fields that had relatively low production in the low deer density area. Deer density, at least on the MDNR's deer per square mile unit give a general indication of production loss that can be expected, but it does not indicate individual field susceptibility to crop loss caused by deer.

Different habitat types available to deer in the 2 deer density areas were confounding factors in determining the effects of the 2 deer densities on crop loss levels. Red kidney bean fields in the high deer density area had relatively more agricultural area and less forested area in their evaluation areas than red kidney bean fields in the low deer density area (Table 24). In addition, the low deer density area had more homogeneous forested areas, in terms of species composition and forest structure, than the high deer density area. Wooded areas in the low deer density area were characterized by relatively more upland hardwood (mostly mature), pine and upland conifer, and opening area and much less lowland hardwood, lowland conifer, aspen, birch, and associated species area than in the high deer density area (Table 24).

Less habitat type variety, particularly of forest types with preferred forage species, in the low density area could have led to increased deer pressure in some bean fields. This was evident in many of the fields that had relatively large crop losses, some of which were greater than losses in fields in the high deer density area.

More information about the effects of deer density related to crop loss could provide more baseline information. It is difficult to discern if production losses were relatively high in the low deer density area or, similarly, if losses were relatively low in the high deer density area. For example, the greater agricultural area available to deer in the high deer density areas (Table 24) could have resulted in a number of effects on production levels.

First, more agricultural area in the high deer density area than in the low deer density area could have resulted in production losses being dispersed and detected over a larger geographic area. Compared to the low deer density area, deer foraging pressure in fields in the high density area could have been somewhat mitigated because more agricultural land was available. Or the deer density could have been great enough in the high density area that there was relatively more deer foraging pressure in all agricultural fields. Second, less production in the low deer density area could have occurred in many fields because areas surrounding bean fields was relatively homogeneous. Losses could have been relatively great if forage in woodland areas, especially preferred species, was relatively less available.

Tart Cherry Orchards

Two orchards were not adequate for determining whether or not deer browsing caused statistically significant levels of tart cherry loss. Long-term exclusion experiments could better assess crop losses and associated costs of decreased yields. Comparing exclosed trees with trees in areas open to browsing, from the time of planting to the time production age is reached, could generate more detailed information.

With the sample size used in this study, levels of browsed CAG twigs were most influenced by spring food quality and the ratio of agricultural area to open area and to the amount of upland hardwood area within evaluation areas. Higher browse use occurred in orchards that had higher spring food SI's and that were surrounded by more opening area and upland hardwood area relative to agricultural area (1993, 1994, and 1993 and 1994 combined models).

The percentage of browsed CAG twigs detected during this project (Table 20) were not enough to kill most tart cherry trees. Percentages of browsed shoots would have to be between 70% and 80% to set back tree growth a minimum of

1 year or cause mortality (J. Nugent, Northwest Horticultural Exp. Sta., Mich., pers. commun.). However, results can be used as an indication of how deer, and the effects of their surrounding habitat, can potentially impact orchard tree growth and production.

Effects of Deer Browsing on Tart Cherry Trees

Browsing is the most common form of damage to orchard trees (Katsma and Rusch 1980) and bud nipping can cause lower tree production (Austin and Urness 1989). Orchardists are most concerned with money lost from retarded tree growth and subsequent production delays that can be caused by deer browsing. Once trees reach production age (usually 6-7 years), most cherry growers feel that deer damage to fruit and new shoots is negligible (orchardists, pers. commun.). Their main concern is levels of browsing on young trees. Carrying costs associated with growing trees and delayed harvests are the economic threat, not the fruit losses.

On older trees, branches are pruned approximately 76.2 cm from the ground so that harvesting equipment can be used to shake cherries from the trees. This pruning height leaves deer with fewer branches within their reach than on unpruned trees. The full growth (ie. branches growing into open spaces) on older trees prevents deer from reaching growth near the trunk so deer browsing is usually restricted to the periphery of trees. Also, any fruit loss from deer is a loss for only that year, whereas the impacts browsing can have on relatively young tree growth is a long-term cost carried by the orchardist.

Young trees, typically considered between the ages of 1-6, are susceptible to deer browsing over their entire structure. Younger trees have fewer shoots per tree than do older trees. The effects of deer browsing, therefore, have relatively more impact on younger trees because deer eat proportionally more of a young tree to get the same biomass intake as from an older tree. Younger trees also grow vigorously, concentrating nutrients in their new shoots. The length of time it takes for a tree to reach production age means that repeated deer browsing can have cumulative effects.

The first 5 to 6 years of cherry tree growth is the development stage where trees are pruned and conditioned to begin harvestable production by the seventh or eighth year. By year 7 or 8 they begin to produce approximately 18.18-27.27 kg (40-60 lbs.). Tart cherry trees do not reach maximum production potential until approximately their ninth year of growth. Peak production usually occurs between 9 and 22 years where each tree can produce from 27.27-45.45 kg (60-100 lbs.) each growing season. One to 3 year trees produce between 0.0 and a few kilograms of cherries. Four year old trees produce about 4.55 kg (10 lbs.) of cherries, 5 year old trees about 6.82 kg (15 lbs.) and 6 year old trees about 9.09 kg (20 lbs.) (Kesner and Nugent, Northwest Horticul. Exp. Sta., Mich., unpubl.).

The first 3 years are critical to tree development. During the first growing season, trees with a 1.27 cm to 1.58 cm diameter are bought from a nursery. The trees are whipped (all lateral branches are removed) during the first growing season so that a leader develops. During the second year, 4 side limbs are chosen to become scaffold branches and these must be 76.2 cm from the ground so that harvesting equipment will later be able to reach each tree's trunk without branches being in the way. During the third growing season, another 2 to 4 branches are chosen as additional scaffold limbs so that 6 to 8 scaffold branches will continue to develop below the leader (Kelsey et al. 1989).

Although young trees are heavily pruned while they are developing to production age, deer browsing can affect their structure. Browsing can interrupt the growth of branches that were to become scaffold limbs. Having fewer than 4 scaffold limbs during the second growing season could result in the scaffolds being as large as the leader which results in a tree having only 2 or 3 limbs and an open center (Kesner and Nugent 1984). If a tree develops fewer than 4 scaffolds, the tree must be re-whipped the following year (Kelsey et al. 1989). Even if the shoot or shoots are partially browsed by deer, the trees' vigor is decreased and orchardists must often wait another year and try to grow those scaffold branches again or plan to select new scaffold branches. Besides pruning trees so they reach maximum production, full production potential is not reached until smaller branches fill in the spaces between the scaffold branches. Consequently, deer browsing may affect yields by delaying the time at which trees would reach full production potential.

Browsing might also alter the nutrient distribution within younger trees. Leaf and bud removal results in decreased carbohydrate reserves and reduced photosynthetic potential as energy that would have otherwise been allocated to new growth goes to new leaf production. Excessive browsing and resulting depleted nutrient levels can lead to both decreased root growth and fruit production (Flyger and Thoerig 1962). If browsing occurs late in the growing season, trees will have lower levels of nutrients to translocate to their roots during the winter. Less nutrient storage in root systems increases the chances of mortality by affecting trees' persistence through the winter and trees' vigor during the following spring. If a browsed tree is in its second or third growing season the likelihood of mortality is higher than if the tree were in its fourth, or more, growing season (J. Nugent, Northwest Horticul. Exp. Sta., Mich., pers. commun.).

The cumulative effects of browsing on young tree development can be costly as interest is carried through the years until trees reach production age. As costs increase during the time until trees reach production age, the costs are spread out over the age of the block or orchard. Since trees that may have had their growth retarded by browsing will not live any longer than trees that had no browsing, the costs for those trees accumulate and are compounded (J. Nugent, Northwest Horticul. Exp. Sta., Mich., pers. commun.).

Contributions Tart Cherry Orchards Made to Deer Habitat Quality, Predictive Models, and Landscape Characteristics Surrounding Orchards

The 1993 predictive model had the greatest predictive ability out of all 3 models. The 1993 and 1994 combined model predicted browse percentages for all data sets better than any of the other models. The 1993 and 1994 combined model could be used as a general indicator of potential browse levels for either year. All models were limited by the small sample size from which models were derived. More predictive models could be created with information from larger sample sizes.

Too many varieties of fertilizers, herbicides, and pesticides were used relative to field and orchard sample sizes to be able to detect if any of those chemicals affected levels of deer browsing on tart cherry trees.

Like alfalfa, tart cherries were a palatable and available spring food. New growth on tart cherry trees provided high quality spring food and older trees provide relatively high quality security cover. The contribution of orchards to deer habitat quality was exemplified by mean HSI's for fall and winter food, HSI's for spring food, fall and winter food SI's for agricultural areas, and spring food SI's for agricultural areas were greatest in evaluation areas around tart cherry orchards (Tables 21 and 22).

The 1994 correlation between HSI's for spring food and browse percentages and the 1994 model supported the idea that crops that provided high quality spring food received greater deer use. Greater browsing intensities occurred in areas that had higher SI's for agriculture during the spring and higher HSI's for spring food.

More browsing occurred when the amount of agricultural area decreased relative to the area in openings (1993 model) and when the amount of opening area increased (Table 39). Relatively high numbers of open hectares could have attracted deer to areas near orchards, but because orchard evaluation areas had the second lowest mean SI's for openings (Table 22), food quality might not have been adequate. Deer could have put increased browsing pressure on available orchards during the spring to compensate for a possible lack of quality forage in openings. Because orchard evaluation areas also had the smallest mean number of agricultural hectares of the 3 crop types (Table 24), deer pressure could have been accentuated in orchards.

Correlations between browse percentages and lowland conifer area and pine and upland conifer area (Table 39) could have been a result of the high quality spring food cherry trees provided. Greater pine and upland conifer area could have held higher concentrations of deer over the winter months. Once snow melted, deer could have filtered out of thermal cover areas and put relatively high pressure on orchards. The positive correlations with the distance to thermal cover could have resulted from poorer quality soils potentially causing less food production in areas dominated by conifer species. Deer might have traveled farther to get to orchards, especially if tart cherry trees are a preferred spring food.

Information from 1993, 1994, and both years combined indicated that more browsing occurred as the length of edge associated with agricultural lands decreased (Table 39) even though agricultural areas surrounding tart cherry orchards had the greatest mean edge diversity indices the greatest mean perimeter length (Table 26 and 27). It was unclear to what extent hiding cover provided by cherry trees affected patterns of deer use in orchards. Orchards had the greatest mean SI's when agricultural areas were added into the security cover equation, and browse use for 1993 and for 1993 and 1994 combined were significantly correlated with that variable (Table 39). It is possible that deer did not restrict their feeding along orchard edges because tart cherry trees provided some cover, making more interior area available for browsing.

Like evaluation areas around red kidney bean fields in the low deer density area, evaluation areas around tart cherry orchards had relatively more wooded area than the high deer density area (Table 23). The combined model's (1993 and 1994) predictive abilities showed that upland hardwood areas influenced levels of browse. Evaluation areas around tart cherry orchards had more upland hardwood area than the other 2 crop types. Evaluation areas around orchards also had the greatest mean edge diversity index associated with upland hardwood stands and the most upland hardwood area relative to agricultural area (Tables 24, 26 and 25). This could have influenced deer orchard use by providing wooded areas that supported higher numbers of deer.

The best indication of natural forage availability came from cover and stem density measurements. Evaluation areas around tart cherry orchards had relatively high stem densities, basal area, horizontal cover, and vertical cover compared to the other crop types suggesting that there was available food (Table 23). Eighty-one percent of the stems were below 1.50 m, also suggesting that there was available browse in wooded areas. Given that natural forage was highly available, trees could have been browsed because tart cherries were preferred over natural forage species in forested areas.

All of the ratios of agriculture to different vegetation types that significantly correlated with browse use levels were negatively correlated (Table 39). This suggested that more browse occurred in tart cherry orchards when there were more vegetation types present in evaluation areas. Again, deer could have selected areas where there was greater habitat variety (Harlow 1984) and edge diversity, especially does who were selecting fawning areas (Nixon et al 1991B). Areas with such variety of habitat types could have held higher numbers of deer that put increased feeding pressure on cherry orchards.

Suggested HSI Model Changes

Suggested improvements for the "White-tailed Deer Habitat Suitability Index Model for the Upper Great Lakes Region" follow in the next few paragraphs. Altering some of the sub-model aspects could make the model a better tool for evaluating deer habitat quality in northern lower Michigan.

For example, the thermal cover equation had no application to this project because the equation is multiplicative and none of the variables are weighted. In its current format, thermal cover HSI's generated for this project were the lowest HSI's. This meant that each area had an overall HSI of 0.0. A weighting scheme should be assigned to the equation so that each of the 5 variables that comprise the SI calculation do not carry the same importance and the equation should not be multiplicative. Conifer stands that may not contain cedar should not be reflected by an HSI of 0.0. Weighting different variables could make the thermal cover sub-model more useful for evaluating deer habitat. Distances to thermal cover (M4V1 variable) was the only thermal cover sub-model value used for regression analyses.

There are also biological reasons that the thermal cover HSI equation should be restructured. Deer are less likely to use heavily forested cover during the winter in this project's agricultural study areas, especially with quality forage provided by crop fields, than they would be farther north, such as in Michigan's upper peninsula, (Rogers 1981, Murphy et al. 1985). The idea that yarding areas are not always used is further supported by 4 deer that were radio-collared during 1994 by Sitar (1996). These 4 deer did not leave their summer home ranges until late February of 1995. The thermal cover equation should be made more flexible so that it better reflects deer biology in a given area.

Security cover HSI's generated for this project are conservative. Stem densities for forested areas should include stems besides trees (trees being defined as dbh $\geq$ 10.0 cm). Restricting values for forested areas to tree density and basal area neglects significant contributions of stems less than 10.0 cm to security cover. The understory in most of the sampled forested stands created more than adequate hiding cover. Most of the stem densities that were calculated for fields and for orchards were calculated from forested areas, not shrub and sapling stands. Stem densities per hectare ranged from 3,400-101,000. The security cover model sets 3,000 stems per hectare at the 1.0 level for shrub and sapling stands. Since all forested areas around both fields and orchards were above 3,000, those woody stems made significant contributions to hiding cover in addition to tree basal area and density.

The width variables for openings and agricultural fields has debatable usefulness for illustrating the degree to which deer will use an opening or a field. First, the model assigns a value to each opening or field, regardless of its distance from potential security cover areas. A field with a 400.0 m maximum width surrounded by 200.0 m of other crop fields would get the same SI as a field with a 400.0 m width that was surrounded by forested area. Both fields in this scenario are not equally useable by deer according to the 180.0 m distance from security cover stated in the security cover sub-model.

Second, the problem associated with width variables on PC ARC/INFO became the definition of what was width and what was length. I attempted to standardize width determinations but many polygon shapes were so irregular that my criteria might not have made biological sense. For example, there were many L-shapes and U-shapes. The widths I calculated for such shapes (taking the longest perpendicular line crossing the longest visualized line through a polygon) were relatively large and therefore reflected lower SI's than what was probably biologically useable to deer. Better width variables could be obtained using the 180.0 m distance to calculate a percentage, or maximum width, of a field or opening that is useable to deer based on the presence of, and distance to, security cover.

Other parts of the model need to be defined and stated more clearly. For example, it should be specified in the spring food sub-model that there is 1 M2V3 variable for openings and 1 M2V3 variable for agricultural areas. The area in openings and the area in agriculture are not combined to derive a single M2V3 suitability index for the final HSI equation. Lack of specific definitions and SI delineations are easily overlooked until the model has to become a useable assessment tool.

The model might be more useful for deer damage applictions if a section was added for weighting agricultural SI equations, as was done in this thesis. By adding such a section, not all agricultural fields within a given coverage have to be digitized and entered into a database. Weighting agricultural areas will provide an index of habitat quality provided by agricultural areas. Also, there is no SI in any of the sub-models for aquatic emergents that are stated as being an important food source on page 210.

Finally, a limitation of many HSI models is the inability of the models to account for some degree of interspersion and juxtaposition of different habitat components (Lancia et al. 1986). Accounting for all land-use types within an evaluation area might alleviate some of this problem. By adding urban land-use to both the fall and winter foods and spring food sub-models, there was some degree of compensation between land-use types that were available and those that were not available to deer. Another way might be to add in equations for the amount of perimeter, or edge (and possibly fragmentation), within evaluation areas.

SUMMARY

Deer caused crop production losses during 1993 and 1994 in the high and the low deer density areas. Patterns of significant production loss in fields can be used to predict where losses will potentially occur and predictive models can be used to describe potential magnitudes of production loss and factors that contribute to those losses. Production loss was most influenced by combinations of ecological factors that related to seasonal deer behavior, crop growth and field characteristics, and surrounding habitat availability and quality.

Overall alfalfa loss ranged from 2.91% to 8.53%. There were no statistically significant ($P > 0.10$) production differences in core areas for any of the harvests. Areas of fields adjacent to agriculture, woodlands, and development had a mix of statistically significant ($P \leq 0.10$) production losses.

Overall production losses of red kidney beans ranged from 8.96% to 10.78% in the high deer density area and from 1.7% to 2.09% in the low deer density area. Only production losses in the high deer density area were statistically significant ($P \leq 0.10$). Production

differences along wooded edges were statistically significant in the high and the low deer density areas. There were no statistically significant ($P > 0.10$) differences observed in the core areas or along agricultural edges.

The amount of browsed CAG twigs in tart cherry orchards ranged from 0.29 to 19.46. There were no statistically significant production differences ($P > 0.10$) between fenced and unfenced areas.

Alfalfa, red kidney bean, and tart cherry crops make significant contributions to white-tailed deer habitat quality. Correlations between production levels and HSI's and SI's suggest that agricultural crops provide relatively high quality food resources for deer from early April through mid-October.

Landscape variables best described production losses. Trends of production losses were most related to the amount of wooded area and the level of spring food quality in evaluation areas. There was less production when evaluation areas had more wooded area, especially if forested areas contained highly selected forage species (such as aspen). The first alfalfa harvests had greater crop losses when areas providing potential thermal cover were closer to alfalfa fields (average distance was approximately 300 m). Woodlands adjacent to fields greatly influenced patterns of production loss in alfalfa fields and in red kidney bean fields. Tart cherry orchards had greater browsing pressure when surrounding areas had more upland hardwood area and herbaceous openland area.

Alfalfa fields had less production when surrounding areas had higher quality spring food. Red kidney bean fields in the high deer density area showed the opposite, with higher crop losses when spring food quality decreased in evaluation areas.

Crop damage control should focus on proactive methods. Shooting permits could be used when deer densities are relatively high while repellents, exclusion devices, or scare tactics could be used on a per field basis if deer densities are relatively low. The predictive alfalfa crop loss model for 1993 and 1994 harvest data combined showed that the percentage of block permits used by landowners can influence crop loss levels. Shooting permit issuances should be coordinated with the timing and patterns of deer migrations.

White-tailed deer damage to agricultural crops in northern Michigan must be viewed from a landscape perspective. Crop damage is not a simple issue of deer numbers or of shooting deer. Ecological factors within the landscape greatly influenced crop loss levels during this study. Compromises must be made among agricultural producers, sportsmen, and state agencies to manage potential deer damage problems.

RECOMMENDATIONS

Solutions to the issues raised by crop damage will never be simple. Each landowner's situation will be specific to his or her financial capabilities and objectives for their land, field location, estimated production loss, surrounding deer habitat availability and quality, and deer density, pressure, and behavior. Management techniques should be related to specific situations and to the recreational objectives of interest groups (Gladfelter 1980).

Many of the farmers who participated in this study thought that block and summer shooting permits were usually effective although they could not guess at the length of time they effectively controlled deer damage. Results from this study did not show a relationship between production losses and percentages of used summer shooting permits.

Unlike the percentages of summer shooting permits used by landowners, the percentages of block permits that were used were correlated with paired plot production differences. The predictive alfalfa crop loss model for 1993 and 1994 combined harvests showed that production loss correlated with greater percentages of used block permits. This could indicate that a single season of block permit use may not reduce deer numbers enough to have measurable decreases in crop loss levels. In areas with relatively high deer densities it might take a few years to reduce the deer population and crop losses.

Block permits should be viewed, and used, as a proactive crop damage control technique. The aim of block permits in Michigan is to target deer in local areas so that there are fewer deer present the following crop growing season. The timing of block permit issuances should be evaluated in conjunction with deer movements in this region (Sitar 1996).

If summer shooting permits are selected as a crop damage control method, they should be issued as early as possible so that they are used as a proactive form of control, not a reactive one. Flyger and Thoerig (1962) stated that damage control techniques should be used early during the spring to decrease damage to cherry crops and trees. deCalesta and Schwendeman (1978) reported that damage control should be attempted early in the growing season for soybeans because the greatest amount of damage occurred during the first week of above ground bean growth.

Farmers may want to consider more active damage control measures, such as exclusion devices (Hyngstrom and Craven 1988, Isleib 1994) or repellents or scare devices (Scott and Townsend 1985, Hyngstrom and Craven 1988, Dudderar and Marlatt 1989, Swihart and Conover 1990), especially if deer populations are relatively low in areas around their fields.

One possible solution is to rotate crops or alter planting patterns so that high value crops are not planted in "hot spots" (Dudderar and Marlatt 1989). "Hot spots" could be considered near large tracts of forest (such as state forest) or within 300 m of potential thermal cover stands (Table 30). Such tactics might alleviate some of the tension with sportsmen who believe farmers are shooting too many deer.

Farmers must also recognize that deer move throughout their annual home ranges. These home ranges may extend beyond 1 or a few agricultural fields (Sitar 1996). Understanding that habitat types within deer home ranges influence magnitudes of production loss is essential to managing the deer crop damage issue. Deer crop damage issues should be addressed by considering landscapes within which damage occurs.

Crops are an available habitat component that provide quality forage. Crop loss patterns in fields depend on whether the crop provides cover as well as forage, on wooded areas adjacent to fields, and on the contributions the crops make to spring food quality. Levels of production loss depend on which habitat types are available to deer, and the quantity and quality of those types. Agricultural producers must recognize that their year round activities within all habitat types used by deer can influence deer behavior and potential crop loss.

As observed in this study, there might be reasons other than deer for a poor crop harvest. For example, it was pointed out to me by one landowner that a second alfalfa harvest was 4 tons less than the first harvest. The farmer attributed the difference to deer. The first harvest was taken during mid-June when spring precipitation had been well below average and the second harvest during mid-July when precipitation had been above average since the end of June. Although precipitation levels did not significantly influence ($P > 0.10$) crop losses from deer, precipitation could significantly influence crop growth. Other factors contributing to production losses must also be considered.

It is unclear what effects enhancing forage quality in openings or in forested areas would have on crop loss reduction. Further research should be conducted to determine what the effects deer habitat manipulations might have on deer behavior and crop loss levels.

It is possible that increasing the quality of forage in natural openings could act as a type of lure crop and decrease foraging pressure in crop fields or orchards. In areas near alfalfa fields or tart cherry orchards, the species planted in natural or created openings would have to be available before, or at the same time, as alfalfa and tart cherry current annual growth. By providing an early growing species or variety, it could become an alternate food source during the time deer are beginning to recover from nutritional stress.

In areas around red kidney bean fields, increasing natural forage in surrounding habitat types could reduce deer foraging pressure in bean fields or it could attract higher numbers of deer that place increased foraging pressure on fields once beans begin to grow. The models generated in this study showed that there was less bean production when the quality of spring food was relatively low (Tables 35 and 36) in the high deer density area, but there was less production in the low deer density area when spring food was more available in areas surrounding bean fields (Table 37). These results suggest that more research should be conducted in order to determine what effects lure crops might have on red kidney bean production, especially when the effects of deer density are taken into account.

A negative effect of introducing additional, nutritious deer food could lead to increased reproduction rates (Mautz 1978) and increased deer densities over the long term. Higher deer densities could then negate the possible benefits of planting vegetation in openings as greater deer numbers place increased pressure on available forage, including crop fields. A study about the effectiveness of lure crops (either agricultural varieties planted in cultivated fields or natural species planted in openings) could provide more information about managing natural openings for the purposes of decreasing agricultural losses.

It is unclear at this time which forest management strategies, coupled with agricultural land management practices, would best decrease crop losses. The predictive crop loss models generally showed that greater area of aspen and birch and upland hardwoods adjacent to crop fields were indicative of greater crop losses (Tables 30, 31, 32, 33, and 38 and the combined second harvest model, the low deer density model for 1993). In this study, it was not possible to determine how stand ages of preferred forage species might have contributed to crop loss levels. Younger stands of aspen, birch, and maple that provide preferred forage could attract higher numbers of deer that also place foraging pressure on agricultural crops. A relative lack of forage in more mature stands could cause deer to compensate and forage more heavily in crop fields.

If further research shows that greater deer numbers are attracted by available preferred woodland forage, stands such as aspen and birch could be allowed to convert to older vegetation types, thereby decreasing preferred forage availability. Conversely, if it is determined that there is a lack of forage in more mature forested stands that leads to exacerbated crop losses, then farmers and biologists could investigate increasing the availability of alternative deer forage such as lure crops, enhancing forage quality in openings, and logging to induce early successional species (such as aspen) growth. Ground truthing some of these stands, or affixing stand ages to MIRIS codes when maps are digitized into GIS systems, could provide more information about natural forage availability and its effects on crop loss levels.

The information generated from this project can be incorporated into MDNR deer management decisions and shared with agricultural producers for planning crop management practices. Reducing crop damage in Michigan will require a cooperative effort among stakeholders. First, people must recognize the diversity of landscape characteristics that influence crop losses. Second, people should consider alternative land-use practices that might reduce deer damage to crops.

APPENDICES

APPENDIX A

Prorated costs associated with delayed tart cherry tree growth - from "Producing Tart Cherries", Michigan State University Extension Bulletin E-1108 (Kelsey et al. 1989)*

Table 40. Total establishment costs including interest, for 4.05 ha of tart cherries, in northwestern Michigan (1989).

Year	Growing cost	Your farm	Interest	Your farm	Annual total	Your farm	Accumulated cost	Your farm
Site preparation	$3,000.00	---------	$950.00	---------	$3,950.00	---------	$3,950.00	---------
Planting year	$11,483.60	---------	$1,769.18	---------	$13,252.78	---------	$17,202.78	---------
Year two	$3,349.40	---------	$2,687.75	---------	$6,037.15	---------	$23,239.93	---------
Year three	$3,794.90	---------	$3,313.74	---------	$7,108.64	---------	$30,348.57	---------
Year four	$4,062.40	---------	$4,037.98	---------	$8,100.38	---------	$38,448.94	---------
Year five	$4,348.90	---------	$4,862.34	---------	$9,211.24	---------	$47,660.18	---------

*Appendix A was taken from Table 7 in Kelsey et al. (1989)

APPENDIX B

A White-tailed Deer HSI for the Upper Great Lakes Region

****DRAFT****

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A habitat suitability index (HSI) model was developed for white-tailed deer in the Upper Great Lakes Region to assist land managers in assessing and providing for deer habitat in land management practices. This model evaluates deer habitat via 4 distinct sub-models, each dealing with a critical habitat component: Fall and Winter Food, Spring Food, Security Cover, and Thermal Cover. Habitat suitability for each critical component is determined by mathematical equations relating variables that contribute to the habitat component. An overall HSI score quantifying the quality of deer habitat in the evaluation area is then determined as the lowest suitability score of the 4 component sub-models. Quantifying habitat quality for key species such as deer greatly aids land managers in accounting for the habitat needs of wildlife in land management decisions, and assessing the potential impacts of land management decisions on wildlife.

The white-tailed deer are the most popular big game animal in North America (Halls 1978). Highly prized as venison, as a trophy, and for viewing, it is one of the most valuable and important wildlife species in the Upper Great Lakes Region (UGLR). Consideration of the habitat needs of white-tailed deer is therefore extremely important in land management planning.

Although well quantified, the habitat needs of deer have not been extensively modelled. Deer inhabit a broad range of climatic and vegetative conditions across their range

(Halls 1978). Due to this diversity, modelling of deer habitat must be localized. Models that are too geographically broad will be so inclusive as to be trivial. Similarly, models too narrow in focus will lack applicability to any area outside the narrow boundaries. This model attempts to evaluate habitat quality for deer in the UGLR in general, and the Huron-Manistee National Forest, Michigan, in particular. Modelling at this geographic level maximizes model utility while maintaining model complexity within reasonable constraints.

The habitat suitability index model presented here involves the assessment of deer habitat via 4 distinct and independent sub-models, each of which deals with a critical element of deer habitat. These 4 sub-models are:

(1) FALL AND WINTER FOODS

(2) SPRING FOODS

(3) SECURITY COVER

(4) THERMAL COVER

Deer require all 4 of these habitat components for existence in most of the UGLR. Evaluation of each critical element of deer habitat via a unique sub-model assures that each life requisite will be given maximum consideration in the evaluation of deer habitat suitability in the UGLR.

GENERAL INFORMATION

White-tailed deer foods follow similar seasonal patterns throughout the Upper Great Lakes Region, despite local differences in vegetation (Rogers et al. 1981). Browse constitutes the primary food source, mainly because it is the only source available year round (Blouch 1984). Other categories of common deer foods include conifer needles, evergreen forbs, deciduous leaves, non-evergreen forbs, grasses, fruit, and fungi (Rogers et al. 1981). Grain residues left in fields after harvest are heavily utilized by deer from September to April

(Gladfelter 1984).

Spring/Summer Foods

Spring foods of deer consist principally of herbaceous vegetation (Healy 1971, Rogers et al. 1981). The most common foods include grasses, sedges, basal rosettes of perennial forbs, and emergent bracken fern (McNeill 1971). Grassy openings are especially important at this time of year (McCafferty and Creed 1969), as are old fields, roadsides, and powerline right-of-ways (Rogers et al. 1981). As spring progresses, new green grasses, emerging forbs, and new leaves of trees and shrubs eventually make up 90% of a deer's diet (Pierce 1975, Rogers et al. 1981). These foods are both nutritious and easily digestible, providing the high quality diet necessary for both survival and reproduction in the face of increased spring metabolic rates (Verme 1963, 1969; Verme and Ullrey 1972).

During late spring-early summer, deer feed heavily on aquatic emergents (Rogers et al. 1981). These plants are nutritious and may provide a source of sodium and other important nutrients for pregnant and lactating does (Jordan et al. 1974).

Summer deer foods consist of leaves of non-evergreen terrestrial plants, mushrooms, and fruits (Kohn and Mooty 1971, McCafferty et al. 1974). Succulent new leaves are the principal component of deer diets during this period (Blouch 1984). Leaves of aspen seedlings < 1 year old are especially preferred.

Fall and Winter Foods

As summer progresses into fall, use of grasses increases while leaf and forb use declines (Blouch 1984). During good mast years, acorns, beechnuts, and other hard mast are highly preferred fall/winter foods. Deer shift their diets to woody browse with the first frosts; the shift to browse is usually complete with the first snows (Blouch 1984). In the George Reserve of Michigan, 7cm of snow changed the diet of deer from 63% to 0%

herbaceous (Coblentz 1970). Where available, agricultural crops, especially corn and soybeans, can also make up a major portion of a deer's fall and winter diet (Nixon et al. 1970).

Woody browse forms the bulk of deer winter diets (Rogers et al. 1981). Northern white-cedar, red maple, eastern hemlock, American mountain-ash, and alternate-leaved dogwood are all highly preferred browse species (Blouch 1984). Eastern white pine, yellow birch, mountain maple, serviceberry, and jack pine are slightly less preferred, followed by aspen, northern red oak, beaked hazelnut, paper birch, balsam fir, and red pine. Last resort foods include speckled alder, black and white spruce, and tamarack. Although cedar is highly preferred, conifer needles are typically a poorer diet than most woody browse (Rogers et al. 1981). Conifer needles comprise only a small proportion of the diets of healthy deer; needles can comprise up to 50-60% of stomach contents of starved deer (Aldous and Smith 1938, Dahlberg and Guettinger 1956).

A prolonged diet of woody browse causes malnutrition and starvation in deer (Mautz 1978). Browse is typically poor nutritionally, and deer will lose weight on a steady browse diet even if browse is available ad libitum (Ullrey et al. 1964, 1967, 1968; Verme and Ullrey 1972, Grigal et al. 1979). As a result, at winters end deer fat reserves are usually depleted and deer are nutritionally stressed (Verme 1969, Mautz 1978).

COVER

Security Cover

Cover can be defined as any structural feature of the environment that is used as protection from the environment (thermal cover) or from predators (security cover) (Boyd and Cooperrider 1986). Security cover is used for protection from predators and/or humans. White-tailed deer are hiders; they rely on suitable vegetative cover to conceal themselves from predators, but they can also run effectively through dense vegetation to escape predators (Boyd and Cooperrider 1986). Thus, security cover for deer consists of dense vegetation in which the animal can conceal itself and flee, if necessary.

Thomas et al. (1979) noted that optimal habitat for deer requires hiding cover, perhaps because it gives the animals a sense of security. Thomas et al. (1979) defined security cover (hiding cover) as vegetation capable of hiding 90% of a standing adult deer at a distance of $\leq$61m. Most use of security cover by deer tends to occur within 183m of the edge between cover and forage areas (Reynolds 1966, Harper 1969, Thomas et al. 1979).

Thermal Cover

In the UGLR, snow depth, low temperatures, and lack of protection combine to limit the northern range of deer (Halls 1978, Blouch 1984). Snow limits deer movements and covers food; cold temperatures and wind combine to drive deer energy reserves down. In response to this environmental stress, deer tend to concentrate (yard) in heavy coniferous cover, where snow depth, wind, and radiant heat loss are minimized (Blouch 1984).

White-tailed deer movements begin to be restricted by snow when it reaches depths of 36-43cm (Kelsall 1969). Deer may travel considerable distances to reach suitable thermal cover. Distances traveled in the UGLR range up to 10-48+km (Rongstad and Tester 1969, Dahlberg and Guettinger 1956, Verme 1973).

Many factors determine what constitutes adequate deer thermal cover. Weber et al. (1983) found 4 variables to accurately predict deer use of potential thermal cover areas in New Hampshire: (1) area site index, (2) stand basal area, (3) softwood crown closure, and (4) stand size. These 4 variables were able to predict site utilization with a precision of 95%. Additionally, species of conifer has been shown to be an important factor in deer yard quality in the UGLR (Blouch 1984).

In New Hampshire, site index showed the greatest variation between conifer stands utilized as deer yards and those not used (Weber et al. 1983). Site index is important in deer yard quality, as the largest trees with the most fully developed and well shaped crowns grow where site index is highest. This results in high softwood crown-closure. For northern white cedar, deer yards in New Hampshire averaged 17.4m in site index; non-deer yards averaged 15.1m (Weber et al. 1983). Site indices for northern white-cedar in the UGLR are lower than in New Hampshire deer yards, typically 12m on the best sites, and 5m on poorer sites (Johnston 1977).

Total basal area of a conifer stand was found to be inversely related to winter deer utilization (Weber et al. 1983). Deer apparently seek out canopy openings to benefit from incoming radiant solar energy (Aldous 1941). Openings also provide a potential source of food; saplings and young sprouts often grow in areas receiving direct sunlight (Weber et al. 1983). Conifer stands utilized as deer yards in New Hampshire averaged 49.3m^2/ha of total basal area (34.5-67.5), while non-deer yards averaged a higher 57.7m^2/ha (42.2-72.8) (Weber et al. 1983).

Softwood crown closure has long been recognized as an important component of winter deer habitat (Verme 1965, Nowosad 1967, Kramer 1970, Blouch 1984). Complete conifer canopy closure, however, is not necessary and may be undesirable for deer yards (Aldous 1941, Weber et al. 1983). Euler and Thurston (1980) found that deer use declined in eastern hemlock stands when crown closure increased beyond 71%. Weber et al. (1983) found deer yards in New Hampshire to be characterized by softwood crown closures averaging 66.7%. Non-deer yards averaged 54.3%. Thus, although high softwood crown closure is important in snow depth and wind velocity reduction, total closure is undesirable as it negates the patchiness associated with food production and solar hot spots previously noted.

Weber et al. (1983) also found stand size to be an important factor in deer yard use. Deer yards in New Hampshire were larger than non-deer yards (mean of 63.6 ha versus 40.7 ha). Large areas are more likely to be located by migratory animals, and support greater numbers of deer.

Conifer species is the final important factor in deer yard quality. Northern white cedar provides the best cover and forage, and is heavily utilized (Blouch 1984). Eastern hemlock, jack pine, balsam fir, and other dense stands of upland conifers are also utilized where cedar or mixed conifer swamps are lacking.

MODEL JUSTIFICATION/APPLICATION

This white-tailed deer HSI model is composed of 4 distinct sub-models:

(1) FALL/WINTER FOODS

(2) SPRING FOODS

(3) SECURITY COVER

(4) THERMAL COVER

The model assesses the quality of the evaluation area for each sub-model habitat component independently. The final HSI value for deer is based on a most critical limiting factor theorem: whichever sub-model HSI value is the lowest (most limiting) will be the overall HSI value for deer in the evaluation area. The reasoning behind this is that each critical habitat component associated with a sub-model is considered equally important to the well being of deer; thus, a high value for one component(s) cannot compensate for a low value of another.

White-tailed deer home ranges can vary significantly, based on geographic area, climate, annual variation in weather, etc (Marchinton and Hirth 1984). Values reported in the literature ranged from ≤ 59 ha to >520 ha (reviewed by Marchinton and Hirth 1984). Most deer home ranges have radii of less than 1.6 km, however. Therefore, the unit of evaluation for this white-tailed deer HSI model is an area of contiguous habitat of ≥ 2.56 km^2 (256 ha).

MODEL 1: FALL/WINTER FOODS (FWF)

Fall and winter foods in the UGLR consist primarily of woody browse, mast, and selected agricultural crops (Rogers et al. 1981, Blouch 1984). This model assumes that browse is a function of availability and the relative nutritional quality of the site (Fig. 27). FALL/WINTER FOOD suitability should be optimal as available ($\geq$ 1m tall, $\leq$6.3cm dbh) woody stems per hectare reach 5000 (M_1V_1, Fig. 27). Additionally, the nutritional quality of available browse can be related to site quality. This model assumes that higher quality sites (as assessed by site index for red pine or ecological land type phase (ELTP) will produce higher nutritional quality forage (M_1V_2, and alt M_1V_2, Fig. 27). The total suitability index (SI) for woody browse is a mean of the individual values for availability and nutritional quality:

$$SI_{BROWSE} = (M_1V_1 + M_1V_2)/2.$$

The main mast producing species in the UGLR are the oaks. Acorn production is a product of the number of oak trees present, their size, and the diversity of species present, as acorn production within a species can vary greatly annually (Rogers et al. 1981, Armbruster et al. 1987). This model assumes that acorn production will be optimal when oak basal area is $\geq$7.5m^2/ha (M_1V_3, Fig. 28) (Armbruster et al. 1987). Similarly, larger oak trees tend to produce the largest and most consistent mast crops. This model assumes that acorn production will be maximized in trees $\geq$50cm dbh (M_1V_5, Fig. 28) (Armbruster et al. 1987). Production progressively declines as mean diameters drop below 50cm. Below 25cm, oaks are typically too small to yield good acorn crops; hence, suitability drops to 0.0 (Fig. 28).

Three oak groups occur in the UGLR--the white oak group, the red oak group,

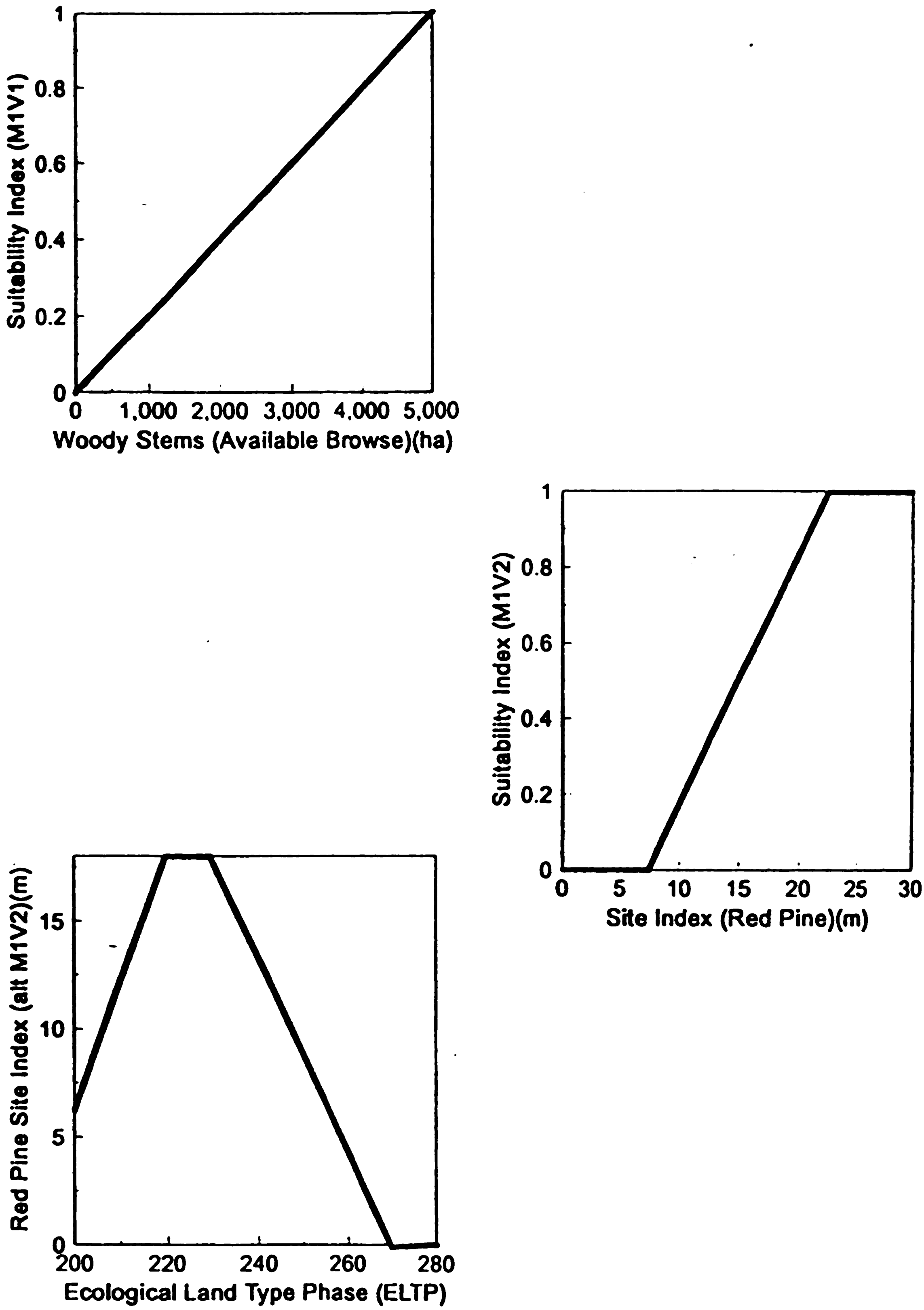


Figure 27. Woody browse variablesfor FALL/WINTER FOODS.

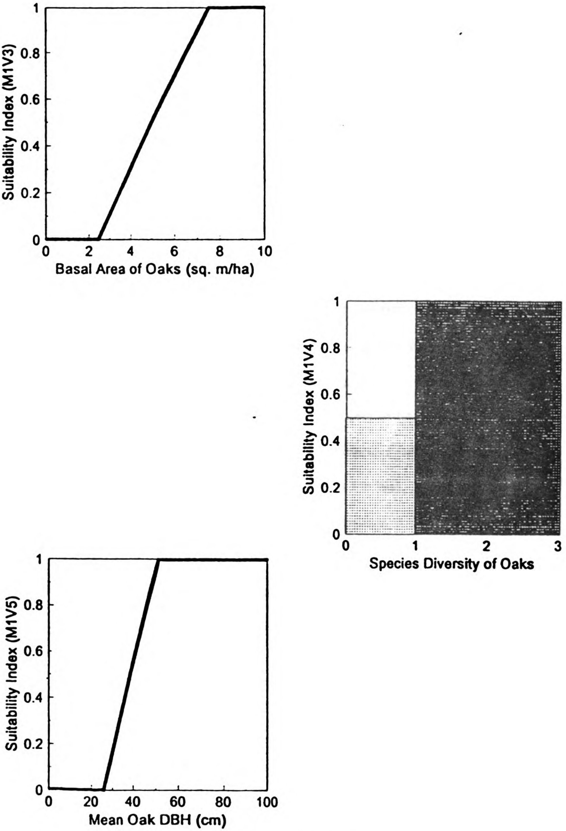


Figure 28. Mast variables for FALL/WINTER FOODS.

and northern pin oak. This model assumes that acorn production will be maximized in areas having > 1 type of oak present (M_1V_4, Fig 28). Areas with 1 type present are assigned a SI of 0.5. If no oaks are present in an area, the area receives a SI of 0.0 for mast production (Fig. 28). The SI for mast as a deer FALL/WINTER FOOD is then calculated as a reduction function of the above 3 variables:

$$SI_{MAST} = M_1V_3 * M_1V_4 * M_1V_5.$$

This model assumes that browse is at least 4X as important in supplying fall and winter foods as is mast, due to the unpredictability of mast production and the continuous availability of browse (Blouch 1984). Therefore, the FALL/WINTER FOOD SI for a forest stand can be determined by a weighted mean of the individual SI's for browse and mast:

$$SI_{FOR\ ST} = (4*SI_{BROWSE} + SI_{MAST})/5.$$

Agricultural fields can also be an important source of FALL/WINTER FOODS for deer in certain areas of the UGLR. Suitability of agricultural fields as a deer FALL/WINTER FOOD source is a function of the size of the field, the crop species cultivated, and tillage practices (Thomas et al. 1979, Armbruster et al. 1987). This model assumes that agricultural fields with a maximum width of ≤ 180m are entirely available to foraging deer and hence receive a SI of 1.0 (M_1V_6, Fig. 29). As the maximum width of a field exceeds 180m deer will not fully utilize the area (Thomas et al. 1979); suitability therefore declines. Fields ≥360m in width will be utilized along their margins only; hence these fields receive a SI of only 0.25.

The crop cultivated also contributes to an agricultural field's suitability as a FALL/WINTER FOOD area. Corn is a highly persistent, highly palatable crop and is assigned a SI of 1.0 (M_1V_7, Fig. 29). Other crops are less persistent and/or less palatable and are assigned lower SI's (Fig. 29). Additionally, management practices affect the availability

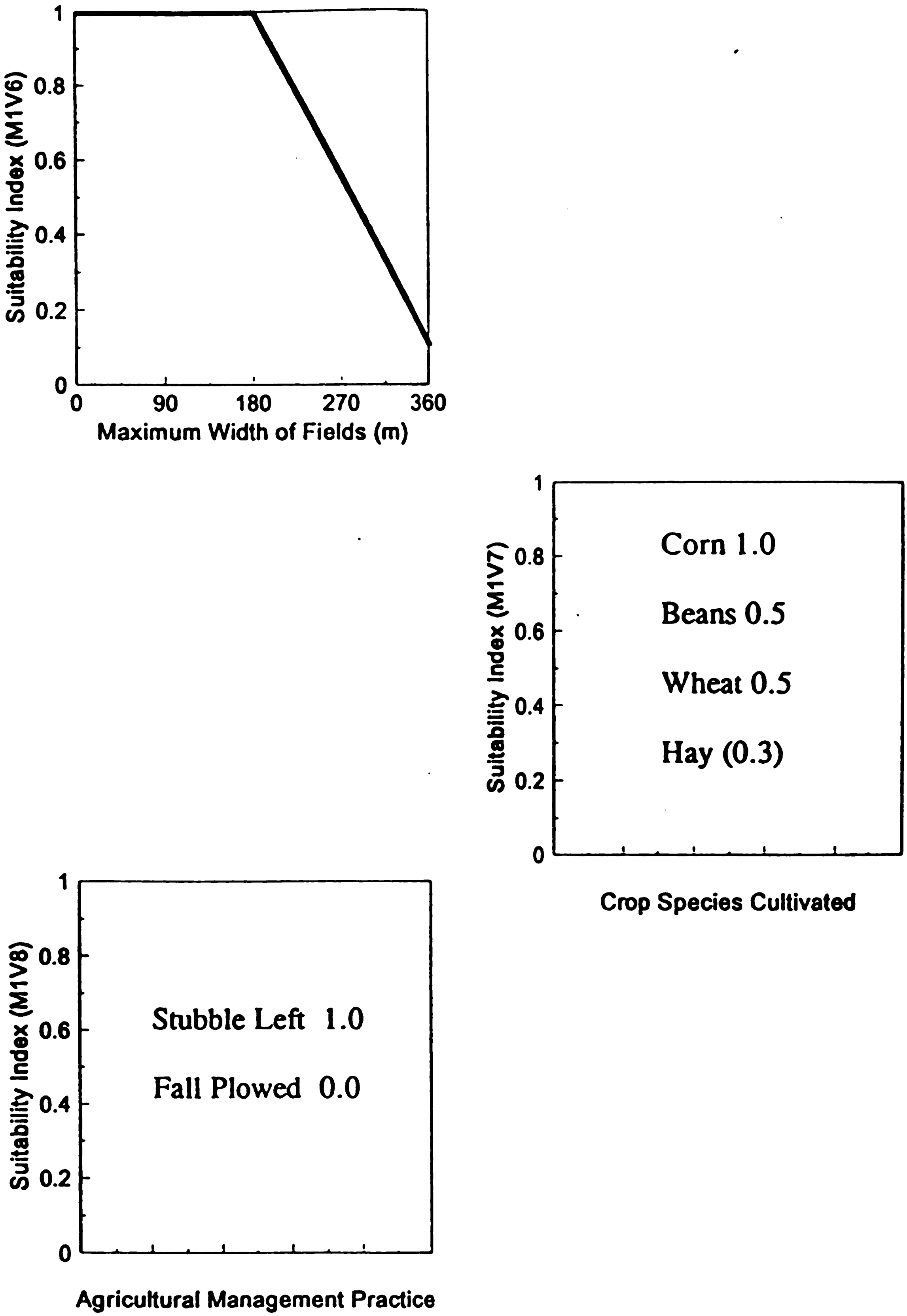


Figure 29. Agricultural field variables for FALL/WINTER FOODS.

of agricultural crops as winter foods. Agricultural fields that are left untilled or under other conservation tillage practices retain maximum crop residues and are assigned a SI of 1.0 (M_1V_8, Fig. 29). Fall plowed fields have little available crop stubble for deer food, and are assigned a SI of 0.0.

The SI for agricultural crops is calculated as a reduction function in the following manner:

$$SI_{AG} = M_1V_6 * M_1V_7 * M_1V_8.$$

Overall suitability of an evaluation area for deer FALL/WINTER FOOD is determined by summing the individual SI's of all forest stands and agricultural fields (i.e. all potential FALL/WINTER FOOD areas) multiplied by the proportional area the total FALL/WINTER FOOD areas that they represent; i.e. SI(FWF area 1)*(area of FWF area 1/total area of all FWF types) + ... + SI(FWF area n)*(proportional area of Stand n), or:

$$SI_{FWF} = SUM_{i=1 \text{ to } n}[(SI\underline{i})*(\text{area of } \underline{i}/\text{total area in FWF})].$$

This value is then modified by assessing the total percentage of the evaluation area in FALL/WINTER FOOD types (M_1V_9, Fig. 30). Sixty percent or more of the total evaluation area in FALL/WINTER FOOD types is considered optimal (Thomas et al. 1979); hence, it is assigned a SI of 1.0. Suitability declines as the percentage of the evaluation area in FALL/WINTER FOOD types drops below 60%. The final HSI for FALL/WINTER FOOD for white-tailed deer is then calculated using the following equation:

$$HSI_{FWF} = SI_{FWF} * M_1V_9.$$

MODEL 2: SPRING FOOD (SF)

Spring foods of deer in the UGLR are chiefly a function of forest openings, agricultural fields, and forest ground cover and understory shrubs (Rogers et al. 1981, Blouch 1984). Spring food production and deer utilization of openings is a function of the openings

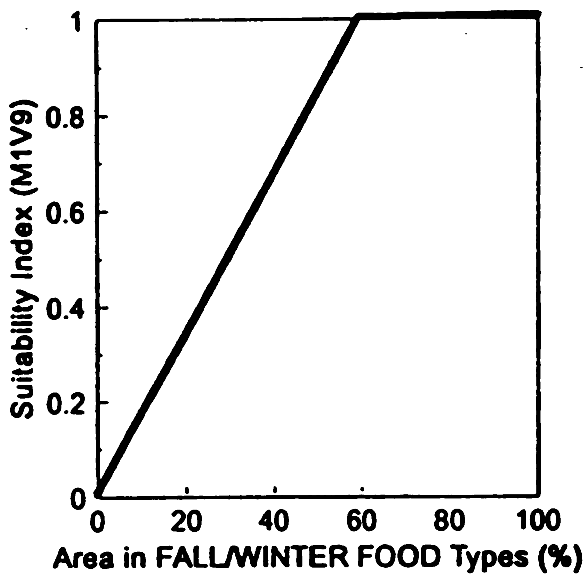


Figure 30. Area function for FALL/WINTER FOODS.

size, the amount of openings in the evaluation area, and the productivity of those openings (Fig. 31). Openings with a maximum width ≥180m will not be fully utilized by deer (Thomas et al. 1979), therefore suitability declines as opening widths exceed 180m (M_2V_1, Fig. 31). Alternatively, size of openings can be substituted for width, with openings being progressively less used as size exceeds 10 ac (alt M_2V_1, Fig. 31). Total herbaceous productivity, although not quantifying deer foods specifically, provides a relative idea of the amount of deer food potentially available (Crawford and Marchinton 1989). Openings with ≥1785 kg/ha likely will produce ample spring foods (M_2V_2, Fig. 32). As total productivity drops below 1785 kg/ha, suitability as SPRING FOOD declines (Fig. 32). The SI of herbaceous productivity can also be estimated utilizing a function combining woody cover and herbaceous ground cover (alt M_2V_2, Fig. 33).

Approximately 10-30% of the evaluation area in openings represents optimal deer habitat (M_2V_3, Fig. 32) (Armbruster and Porath 1980). Below 10%, insufficient openings are present to allow adequate spring food production. If over 30% of an evaluation area is in openings, cover factors are likely to be limiting (Thomas et al. 1979); however, limitations of cover attributes are assessed using the SECURITY COVER sub-model.

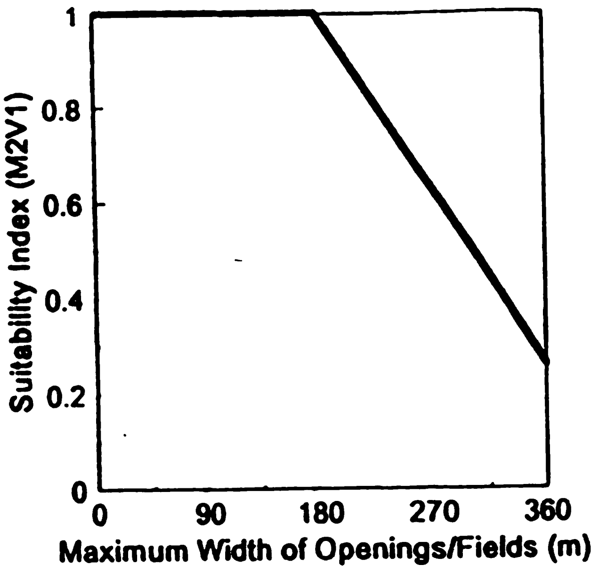
The SI for SPRING FOOD associated with any specific openings is calculated using a reduction function in the following manner:

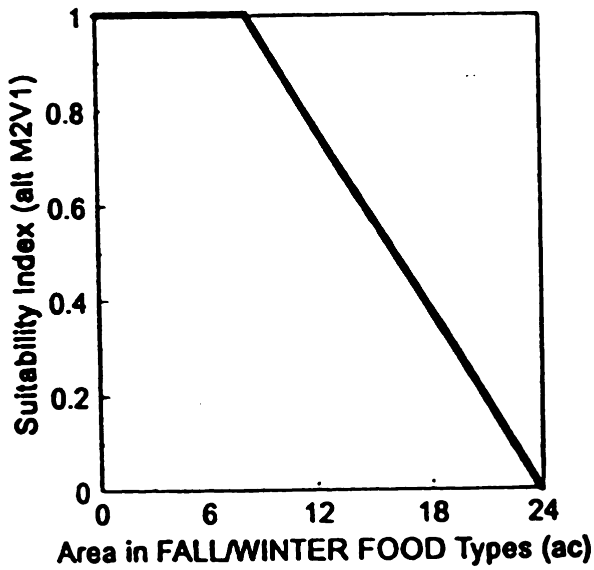
$$SI_{OPEN} = M_2V_1 * M_2V_2 * M_2V_3.$$

The contribution of all openings toward SPRING FOOD is determined utilizing an area weighing procedure:

$$SI_{OPEN} = SUM_{i=1 \ldots n}[(SI_i)*(\text{area of } \underline{i}/\text{total area in openings})].$$

Agricultural fields can also provide spring deer food in the UGLR. Food production and deer utilization associated with agricultural fields can be assessed by





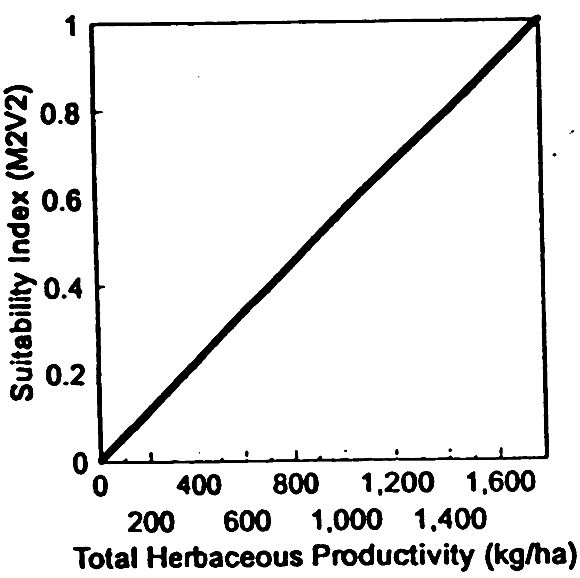


Figure 31. Suitability curves for SPRING FOOD openings components.

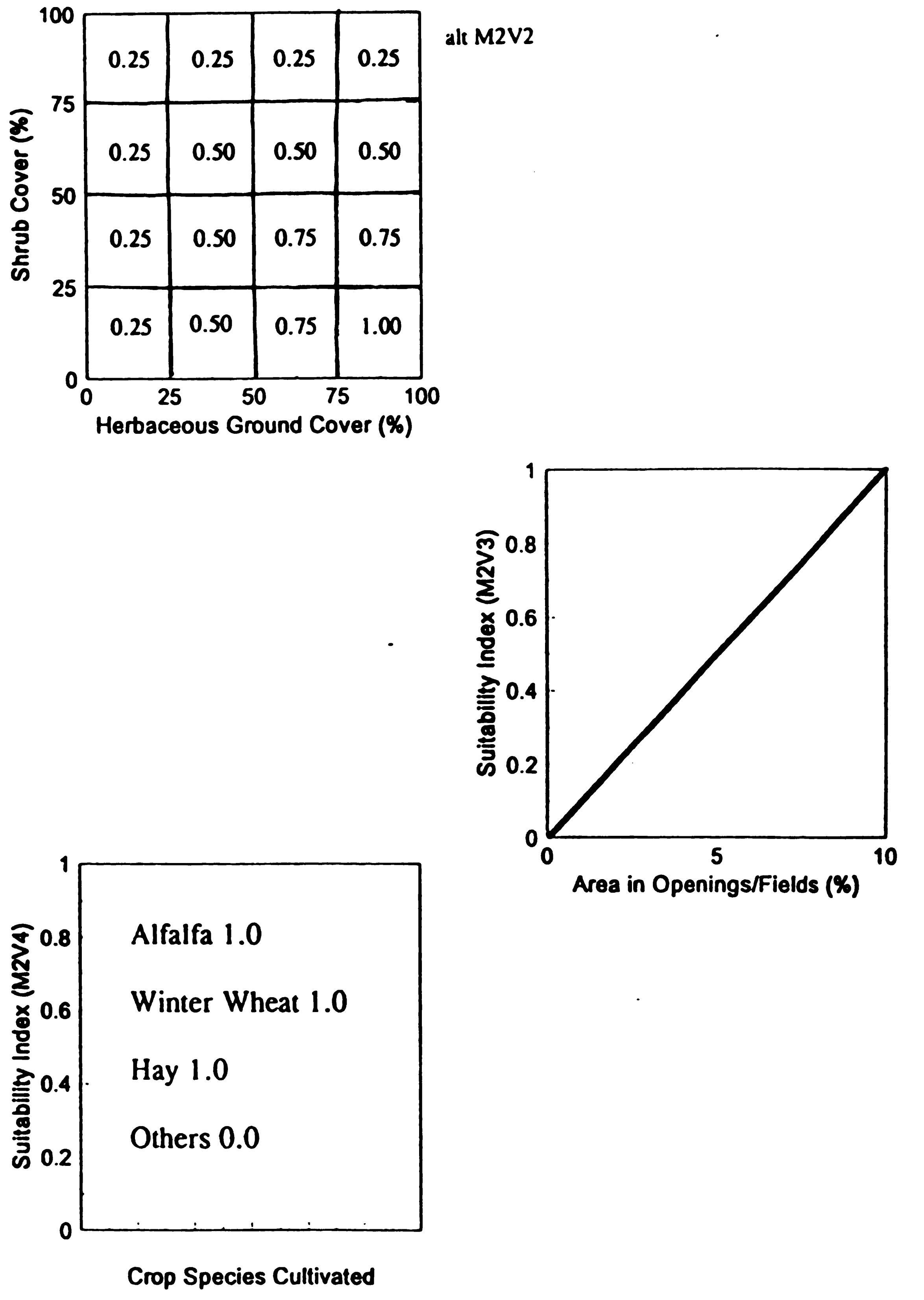


Figure 32. Suitability curves for SPRING FOOD openings components. Suitability of agricultural crops as deer SPRING FOOD.

considering the size of the fields, the percent of the evaluation area in agricultural fields, and the cultivated species. Field size and percent of area in fields is evaluated identically to opening size and percent of area in openings as discussed above (M_2V_1 and M_2V_3, Figs. 31-32, respectively). Crop species is the third agricultural variable (M_2V_4, Fig. 32). Three crops likely to be available to deer in the UGLR in spring include alfalfa, winter wheat, and various hays. All are assigned a suitability value of 1.0. (Fig. 32), as all are likely to be green and actively growing during the critical spring period. All other crops have a suitability of 0.0.

The suitability of a field for SPRING FOOD associated with agricultural production is also evaluated using a reduction function:

$$SI_{AG} = M_2V_1 * M_2V_3 * M_2V_4.$$

The overall suitability of an evaluation area for SPRING FOOD associated with agricultural production is determined by area weighing:

$$SI_{Ag} = SUM_{i=1 \text{ to } n}[(SI_i)*(\text{area of } \underline{i}/\text{total area in ag types})].$$

The final component of spring foods, forest ground layer production, can be evaluated by modifying the SI_{BROWSE} determined for FALL/WINTER FOODS by M_2V_5 (Fig. 33). A forest stand with at least 50% ground cover is assumed to contribute to spring food production. Below 50% ground cover too little is contributed, so the SPRING FOOD index value is set at 0.0. The forest floor (FF) contribution to SPRING FOOD is then calculated in the following manner:

$$SI_{FF} = SUM_{i=1 \text{ to } n}[(SI_{BROWSE}\underline{i} * M_2V_5)(\text{Proportional area of } \underline{i})].$$

Total SPRING FOOD HSI for the evaluation area is then calculated by summing the 3 SPRING FOOD components in the following manner:

$$HSI_{SF} = SI_{OPEN} + SI_{AG} + (0.2 * SI_{FF}).$$

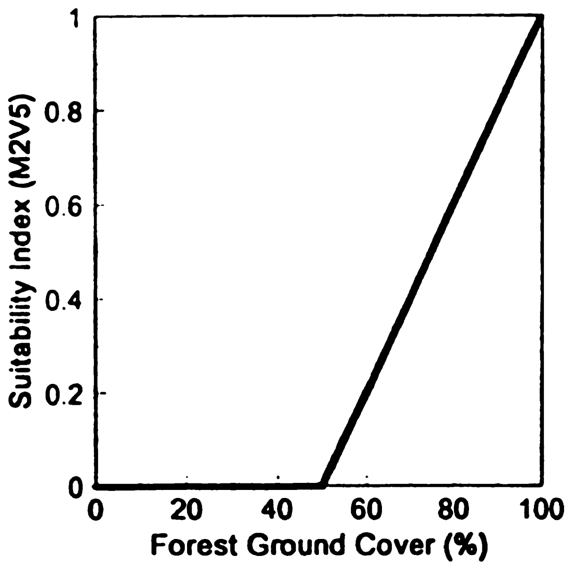


Figure 33. SPRING FOOD suitability of forested stands.

Forest stands are assumed to contribute much less to SPRING FOOD suitability than do openings or agricultural areas; hence, the 0.2 modifier. If the summation of the 3 SPRING FOOD components totals > 1.0, the value is taken as 1.0.

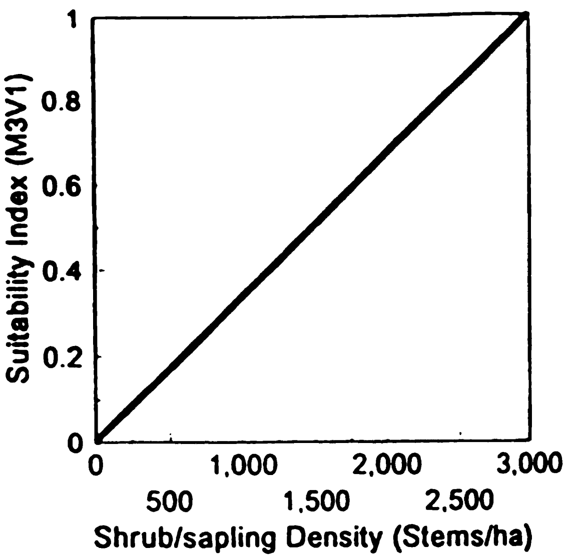
MODEL 3: SECURITY COVER (SC)

Deer need security cover as protection from predators and man (Boyd and Cooperrider 1986). Security cover for deer in the UGLR is principally associated with forested and shrub/sapling stands.

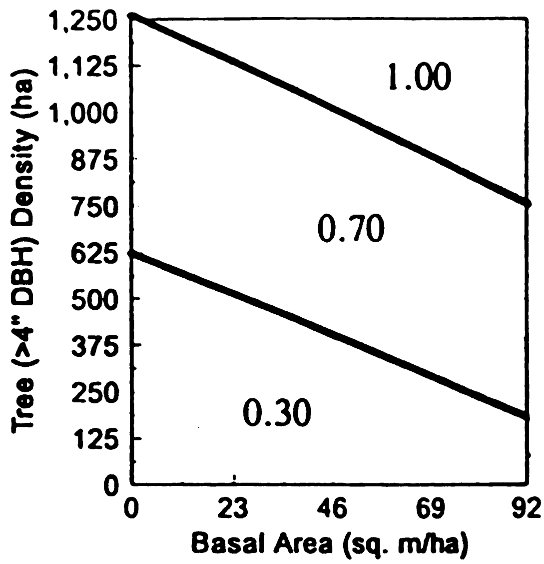
Security cover attributes associated with shrub/sapling stands are primarily a function of the density of woody stems. In the UGLR, shrub/sapling stands with woody densities ≥3000 stems/ha will provide optimal security cover and have a suitability value of 1.0 (M_3V_1, Fig. 34). As mean woody stem densities decrease below 3000/ha, the quality of security cover declines. Patchiness in regeneration/stocking make some areas with a mean of <3000 stems/ha suitable hiding areas, however, so suitability of a shrub/sapling stand as SECURITY COVER remains greater than 0.0 until woody stem densities decline to 0/ha.

The quality of security cover provided by forested stands (mean overstory dbh ≥10.2cm) is a property of stand density and tree size (Armbruster et al. 1987). Smaller trees require higher densities to produce the same degree of concealment as larger trees. The relationship between tree size (represented by total basal area) and tree density and associated suitability values are shown in M_3V_2, (Fig. 34).

The third factor important in assessing the SECURITY COVER attributes of an evaluation area deals with the total amount of SECURITY COVER present. Thomas et al. (1979) felt that at least 40% of an evaluation area should be in security cover for optimal deer habitat in the Blue Mountains of Oregon. This model likewise assumes that ≥40% of an evaluation area should be in security cover types for deer habitat to be optimal (M_3V_3, Fig.



Stand Density/Size Relationship (M3V2)



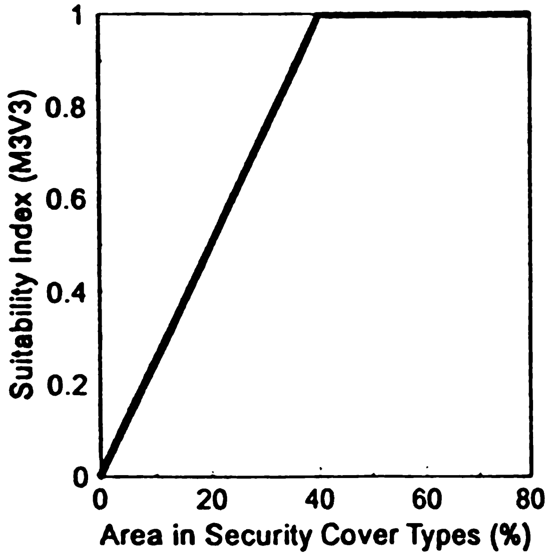


Figure 34. Suitability curves for deer SECURITY COVER variables.

34). As the amount of security cover in an evaluation area drops below 40%, habitat quality declines, as deer lack adequate protection from predation, hunting, and disturbance.

SECURITY COVER in this model is assumed to be an attribute of shrub/sapling stands and forested stands only. Security cover quality is evaluated on a stand by stand basis utilizing M_3V_1 for shrub/sapling stands and M_3V_2 for forested stands. The overall SI for SECURITY COVER for the entire evaluation area is determined by summing the products of each individual stands quality value times the proportion that particular stand contributes area-wise to the area grand total of all SECURITY COVER areas:

$$SI_{sc} = SUM_{i=1 \text{ to } n}[(SI_{STAND}i)*(\text{area of } \underline{i}/\text{total area in security cover})].$$

The overall HSI for deer SECURITY COVER can then be determined by taking the SI_{sc} value calculated above and modifying it by the percentage of the evaluation area that is in SECURITY COVER types (M_3V_3) (Fig 34):

$$HSI_{sc} = SI_{sc} * M_3V_3.$$

MODEL 4: THERMAL COVER (TC)

This model assumes that thermal cover is necessary and utilized every winter by deer in the UGLR, and that it is the duration of use (and not use itself) which is determined by winter severity. This assumption is undoubtedly valid in the northern parts of the UGLR. It is possible that in southern areas, however, thermal cover may not be needed each year.

Habitat suitability in terms of thermal cover can be evaluated in 2 manners with this model. The first method involves simply defining what constitutes adequate deer thermal cover. The second methodology involves assessing the individual quality of each thermal cover area.

Definition Methodology

This model defines thermal cover as any conifer stand (pole size or larger) with ≥75% softwood crown closure that is ≥2 ha in size (Thomas et al. 1979). The presence/absence of such stand(s) is determined on the evaluation area utilizing a distance relationship for suitability assessment (M_4V_1, Fig. 35). If an area(s) satisfying the above definition is located on or within 3.2km of the evaluation unit, the HSI for THERMAL COVER is 1.0. Habitat quality declines as the distance to suitable wintering areas exceeds 3.2 km. Deer in the UGLR will migrate extreme distances to wintering areas--often >48 km (Dahlberg and Guettinger 1956, Rongstad and Tester 1969, Verme 1973). Such extreme migrations are not indicative of optimal habitat, however. That such migrations do occur, however, accounts for the suitability value of 0.1 applied to all thermal cover areas >8 km distant.

Quality Assessment Methodology

The second method of thermal cover evaluation involves quality assessment of each individual thermal cover area. This model assumes that 5 variables can adequately evaluate the quality of deer wintering areas:

(1) Percent conifer canopy closure

(2) Site index for northern white cedar

(3) Size of area

(4) Basal area

(5) Dominant overstory species

Conifer crown closure is assumed to be optimal at 75% (M_4V_2, Fig. 35) (Thomas et al. 1979). Below 25% conifer crown closure, a stand is assumed to be unsuitable as deer thermal cover due to loss of snow reduction and wind reduction attributes (Fig. 35).

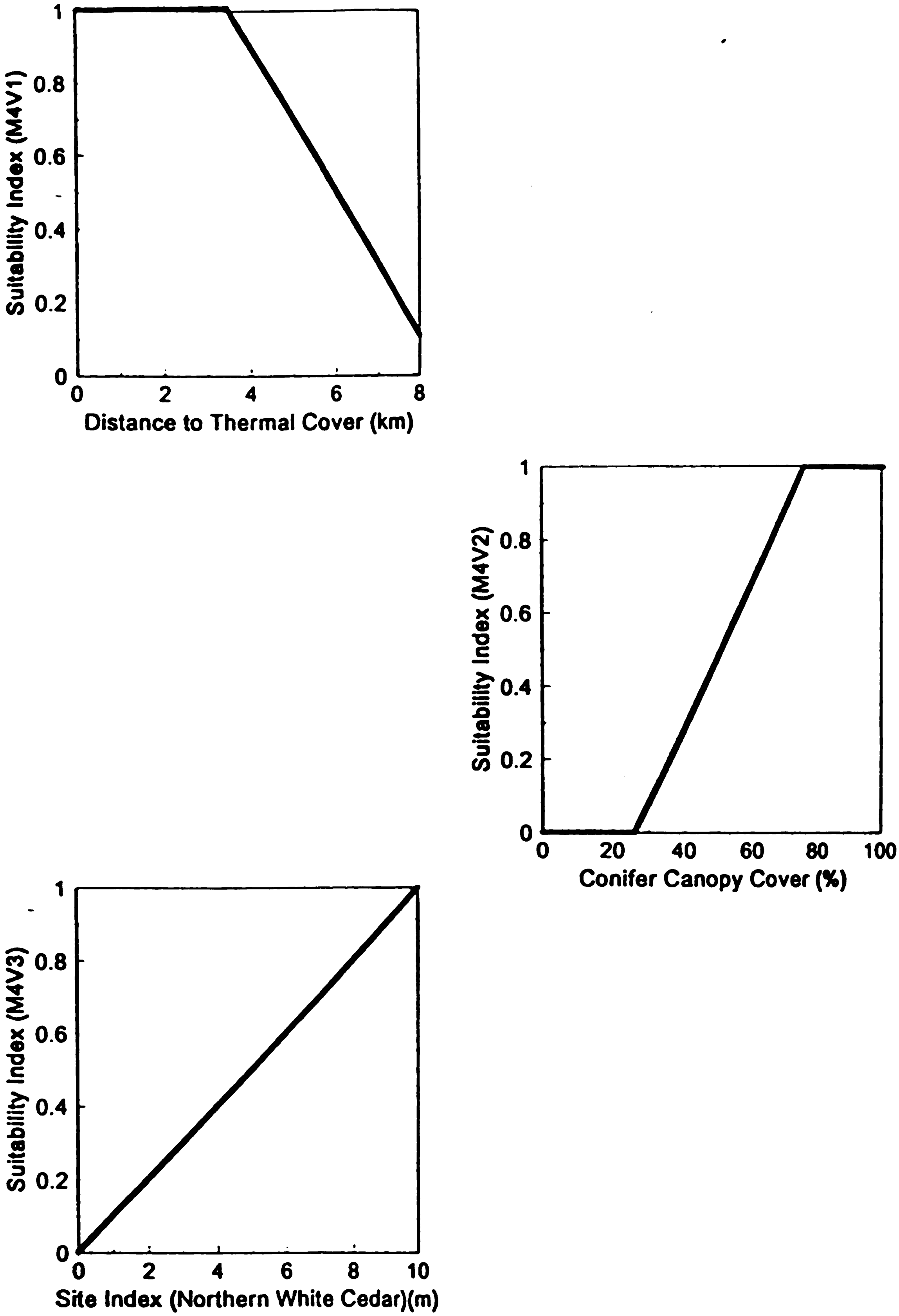


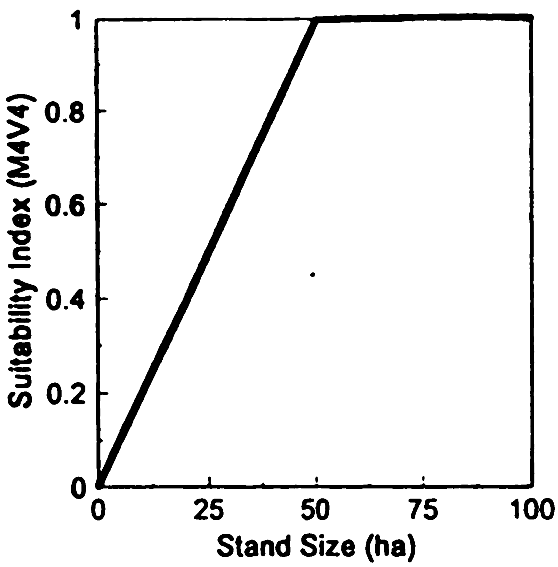
Figure 35. Distance relationship for THERMAL COVER. Suitability curves for THERMAL COVER variables.

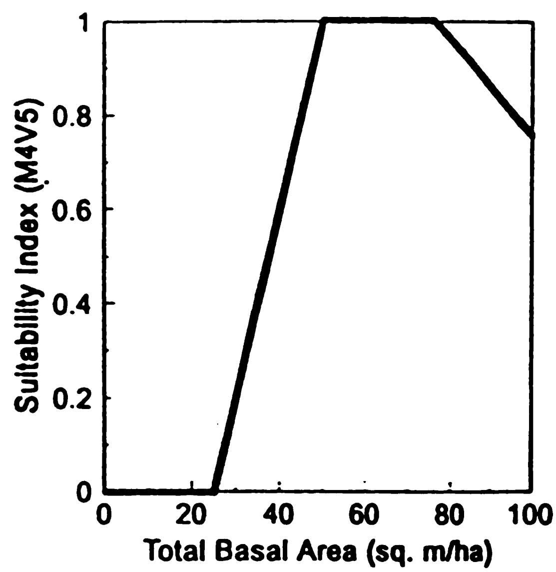
Site index gives a relative assessment of the fertility of an area. This model assumes that a site index of ≥ 10m for northern white-cedar is optimal, as a site of this fertility should allow large full canopied trees to develop, maximizing snow interception and wind reduction (M_4V_3, Fig. 35). Below site index 10m, habitat suitability declines as trees are apt to be smaller and less fully crowned.

Deer yards of 50 ha or larger were found to be optimal in New Hampshire (Weber et al. 1983). This model assumes that areas of similar size will be optimal in the UGLR (M_4V_4, Fig. 36). Areas of this size will winter large numbers of deer and will be easily locatable for migratory deer. Smaller areas are sub-optimal but still provide winter cover (Fig. 36).

Deer benefit from high total basal area in a yard via enhanced wind blocking attributes and forage availability. However, basal areas that are too high result in a lack of small openings (glades), which are important in food production and as "hot spots" where deer can benefit from direct solar radiation (Weber et al. 1983). This model assumes that basal area is optimal between 40 and 60m^2/ha (SI = 1.0; M_4V_5, Fig. 36). Above 60m^2/ha lack of small openings results in less optimal conditions due to lack of the features noted above. Below 40m^2/ha, stands may be insufficiently dense to have optimal wind blockage ability. Stands below 20m^2/ha are too open to provide adequate deer THERMAL COVER (Fig. 36).

The final variable in THERMAL COVER quality assessment is the dominant overstory conifer species. Northern white-cedar is considered optimal for deer winter habitat in the UGLR due to its excellent snow and wind limitation characteristics as well as its forage value (SI = 1.0; M_4V_6, Fig. 36) (Blouch 1984). Spruces, hemlock, and balsam fir are less optimal as THERMAL COVER (SI = 0.7); they do not provide the excellent forage





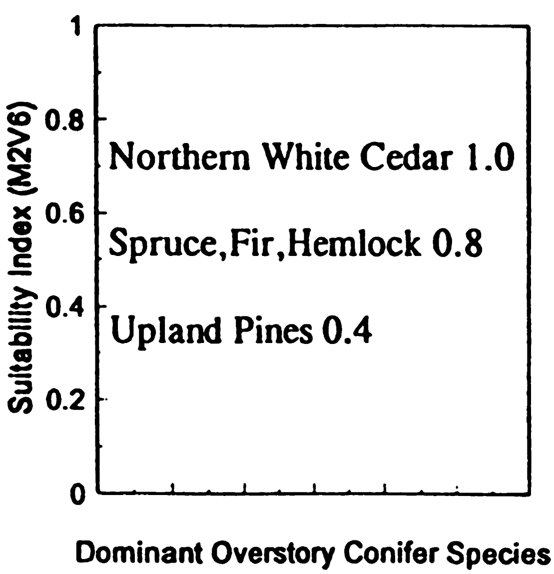


Figure 36. Suitability index curves for THERMAL COVER.

associated with cedar, although their snow and wind blockage characteristics are excellent. Upland pines will be utilized as THERMAL COVER by deer if cedar and other swamp conifers are absent. Upland pines lack the weather modification and/or forage values of the other types, however, and are thus of lower suitability (0.4).

The quality of an area as THERMAL COVER for deer is calculated as a reduction function of the above 5 variables, as each is considered equally important in determining the quality of an area as deer THERMAL COVER. The quality suitability index is thus determined by:

$$SI_{TC} = M_4V_2 * M_4V_3 * M_4V_4 * M_4V_5 * M_4V_6.$$

The HSI for deer THERMAL COVER is then determined by modifying the SI_{TC} calculated above by the distance function (M_4V_1, Fig. 35) discussed under DEFINITION METHODOLOGY in the following manner:

$$HSI_{TC} = SI_{TC} * M_4V_1.$$

WHITE-TAILED DEER HABITAT SUITABILITY

Habitat suitability for white-tailed deer is determined using a minimum function relationship among the 4 life requisite HSIs described above. The overall white-tailed deer HSI for an evaluation area is the lowest HSI calculated for any of the 4 critical habitat requisites, i.e.,

$$HSI_{WTD} = \min \{HSI_{FWF}, HSI_{SF}, HSI_{SC}, HSI_{TC}\}.$$

Determination of deer habitat suitability in this manner makes the assumption that the 4 critical life requisites modelled are non-compensatory. Additionally, assessing deer habitat suitability in this manner allows identification of which life requisite is most limiting in the evaluation area. This can greatly aid in land management efforts by indicating habitat shortcomings in the evaluation area. Future management efforts could then be tailored to correct the limiting factors.

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APPENDIX C

Vegetation categories created for habitat analyses with GIS PC/ARC INFO[a]

Vegetation category	vegetation types or species in category
agriculture	cropland, orchards, bush fruit, vineyards, ornamental horticulture
openings	pasture, herbaceous
wooded	all of the following 5 forested types
upland hardwoods	sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), elm species (*Ulmus*), beech (*Fagus grandifolia)*, yellow birch (*Betulea lutea*), cherry species (*Prunus*), basswood (*Tilia americana)*, white ash (*Fraxinus americana*), red oak (*Quercus rubra*), white oak (*Quercus alba*), black oak (*Quercus velutina*), other northern hardwoods
lowland hardwoods	ash species (*Fraxinus*), elm species (*Ulmus*), soft maple (*Acer saccharinum*), cottonwood (*Populus deltoides*), balm-of-gilead (*Populus gileadensis*), quaking aspen (*Populus tremuloides*), bigtooth aspen (*Populus grandidentata*), balsam poplar (*Populus balsamifera*) white birch (*Betula papyrifera*), other lowland hardwoods
aspen and birch (and associated species)	trembling aspen (*Populus tremuloides*), bigtooth aspen (*Populus grandidentata*), white birch (*Betula papyrifera*), other associated species

pine and upland conifers	white pine (*Pinus strobus*), red pine (*Pinus resinosa*), jack pine (*Pinus banksiana*), conifers scotch pine (*Pinus sylvestris*), other pines, white spruce (*Picea glauca*), black spruce (*Picea marinara*), balsam fir (*Abies balsamea*), douglas fir (*Tsuga ??*), tamarack (*Larix laricina*), hemlock (*Tsuga canadensis*), other associated species
lowland conifers	northern white cedar (*Thuja occidentalis*), black spruce (*Picea mariana*), tamarack (*Larix laricina*), balsam fir-white spruce (*Abies balsamea-Picea glauca*), balsam fir (*Abies balsamea*), jack pine (*Pinus banksiana*), other lowland conifers

[a]species listed in vegetation categories are taken from the Michigan Department of Natural Resources' "Land Use - Forest Cover Legend" and on "Forest Classification" that list species by MIRIS code, (MDNR, Lansing, MI)

APPENDIX D

Landowner Telephone Survey

1) Which seed variety is your crop?

2) a) What were 1993 fields planted with in 1994?
   b) What were 1994 fields planted with in 1993?

3) Which, if any, fertilizer, herbicide, or pesticide did you use during 1993 and 1994?

4) How many times did you apply fertilizer, herbicide, or pesticide? If so, at what time of year were they applied?

5) How much fertilizer, herbicide, or pesticide did you apply?

6) Do you irrigate? If so, how often?

7) a) Do you plant lure crops? If so, what crop type and seed variety do you plant?
   b) Where was the lure crop planted in relation to production fields?

8) Which, if any, crop damage control methods did you use?

APPENDIX E

Field and orchard morphological characteristics

Table 41. Mean field and orchard morphological characteristics for alfalfa fields, red kidney bean fields, and tart cherry orchards during 1993 and 1994.

	% Ag (SE)	% Wooded (SE)	% Dev (SE)	Perim (SE)
Alfalfa				
1st harvest 1993	40.55 (6.92)	42.64 (9.27)	12.09 (5.25)	1360 (108)
2nd harvest 1993	44.13 (4.97)	39.31 (6.91)	15.81 (4.88)	1413 (126)
1st harvest 1994	30.65 (6.85)	54.95 (12.29)	15.15 (3.39)	1255 (79)
2nd harvest 1994	33.71 (4.76)	51.12 (4.50)	15.47 (2.83)	1291 (90)
Overall mean	37.26 (5.35)	47.01 (6.29)	14.63 (1.48)	1330 (61)
Red kidney beans				
High density 1993	34.50 (6.14)	55.50 (6.61)	10.00 (3.74)	1634 (260)
High density 1994	50.70 (8.43)	35.80 (8.95)	13.50 (4.19)	1704 (234)
Overall mean	43.05 (7.65)	45.65 (9.85)	11.75 (1.75)	1669 (35)
Low density 1993	30.75 (11.45)	51.38 (10.73)	17.63 (6.15)	1749 (250)
Low density 1994	35.57 (10.50)	41.57 (8.22)	22.86 (8.56)	2401 (325)
Overall mean	33.16 (2.41)	46.48 (4.91)	10.25 (7.39)	2075 (326)
Tart cherry orchards				
1993	73.00 (1.85)	27.00 (5.93)	0.0 (0.0)	1631 (614)

Table 41 (cont'd).

	% Ag (SE)	% Wooded (SE)	% Dev (SE)	Perim (SE)
1994	73.75 (1.85)	26.25 (1.85)	0.0 (0.0)	1647 (774)
Overall mean	73.38 (0.38)	26.63 (0.38)	0.0 (0.0)	1639 (8)

% Ag percent of field or orchard perimeter adjacent to agriculture

% Wooded percent of field or orchard perimeter adjacent to wooded areas

% Dev percent of field or orchard perimeter adjacent to development

Perim perimeter length of field or orchard

APPENDIX F

Precipitation levels associated with alfalfa paried plot production differences for the second harvest during 1993

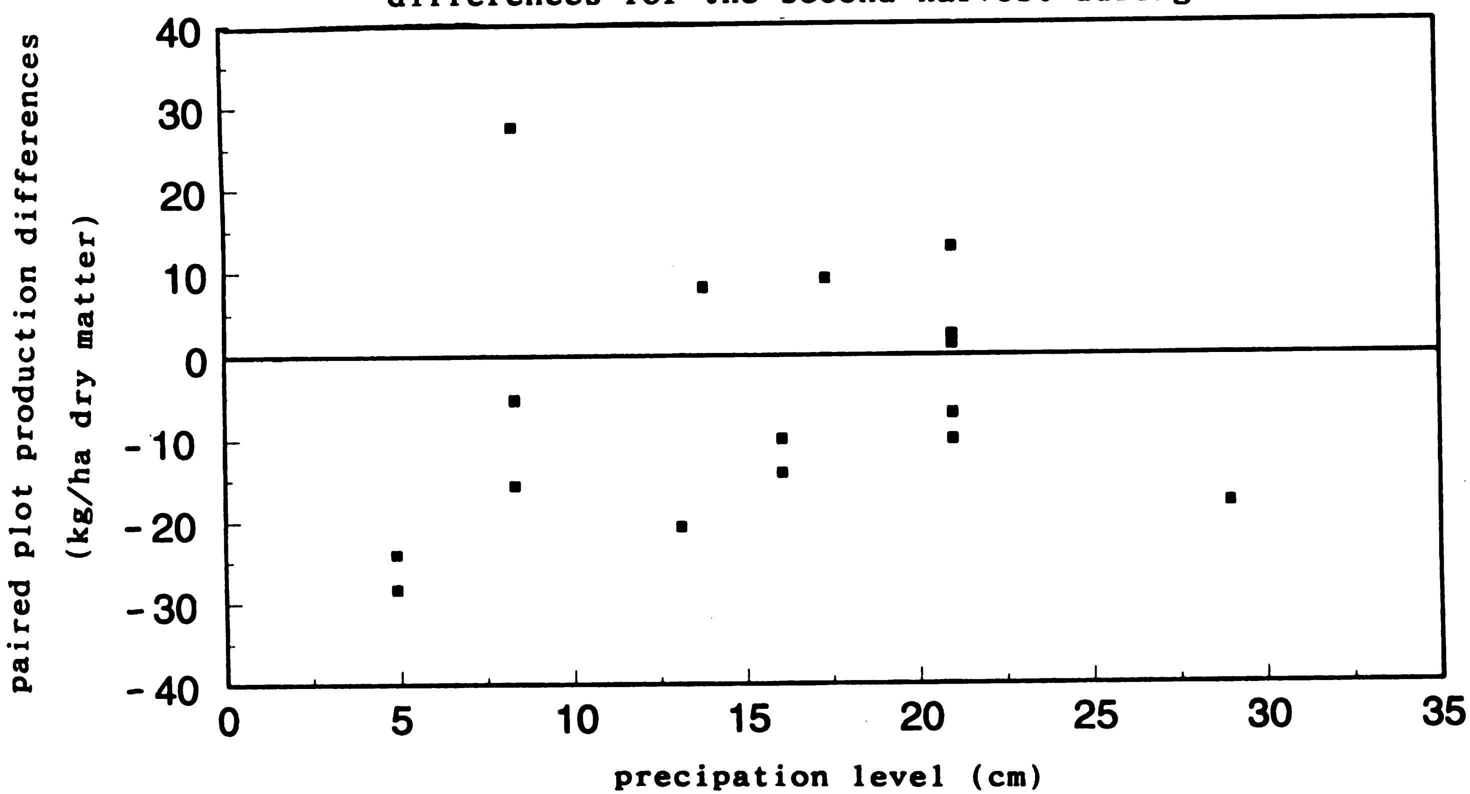

Figure 6. Precipitation levels associated with alfalfa paired plot production differences for the second harvest during 1993 in northern lower Michigan.

APPENDIX G

Observed and predicted paired plot production differences for the first alfalfa harvests

Table 42. Observed and predicted production differences (kg/ha), in descending order (negative numbers represent production losses), between exclosed plots and plots open to foraging for the first 1993 alfalfa harvest model, the first 1994 harvest model, and for the combined first harvest model.

H193		H194		Combined	
Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
256.20	251.36	560.00	571.97	560.00	543.84
139.60	115.50	180.70	128.58	256.20	82.73
51.80	62.33	138.90	106.48	180.70	72.27
3.00	4.63	130.40	91.27	139.60	61.02
-60.80	-44.03	35.20	47.27	138.90	11.65
-133.20	-121.79	18.50	40.38	130.40	6.69
-144.60	-132.55	6.50	21.11	51.80	0.12
-181.50	-186.64	-20.80	-16.18	35.20	-4.84
-270.30	-263.19	-35.40	-59.25	18.50	-23.07
-270.90	-279.93	-94.10	-101.76	6.50	-33.49
-307.80	-324.20	-99.60	-105.42	3.00	-43.33
		-106.60	-135.98	-20.80	-65.65
		-155.80	-143.10	-35.40	-67.01
		-181.90	-150.85	-60.80	-68.72
		-187.10	-175.17	-94.10	-80.23
		-201.40	-239.99	-99.60	-89.44
		-313.70	-262.36	-106.60	-95.00
		-349.20	-339.59	-133.20	-95.42
		-415.80	-385.80	-144.60	-103.81
		-994.30	-977.11	-155.80	-109.51

Table 42 (cont'd).

H193		H194		Combined	
Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
				-181.50	-111.78
				-181.90	-114.93
				-187.10	-115.92
				-201.40	-122.27
				-270.30	-128.67
				-270.90	-167.86
				-307.80	-195.65
				-313.70	-245.74
				-349.20	-370.35
				-415.80	-429.07
				-994.30	-900.53

H193 1993 first harvest model
H194 1994 first harvest model
Combined combined 1993 and 1994 first harvest model
Obs observed difference (kg/ha)
Pred predicted difference (kg/ha)

APPENDIX H

Observed and predicted paired plot production differences for the second alfalfa harvests

Table 43. Observed and predicted production differences (kg/ha), in descending order (negative numbers represent production losses), between exclosed plots and plots open to foraging for the second 1993 alfalfa harvest model, the second 1994 harvest model, and for the combined second harvest model.

H293		H294		Combined	
Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
303.40	157.48	173.90	137.06	303.40	192.64
115.30	133.42	171.50	78.96	173.90	53.12
99.70	128.54	80.50	-10.47	171.50	52.03
88.70	64.73	16.20	-24.11	115.30	51.73
26.10	33.99	-44.80	-37.21	99.70	50.35
12.30	19.91	-53.80	-40.45	88.70	36.60
-53.10	-10.45	-79.10	-61.32	80.50	21.87
-77.10	-38.61	-93.90	-64.49	26.10	14.16
-99.90	-76.59	-99.20	-71.76	16.20	-18.86
-111.00	-98.73	-138.40	-97.03	12.30	-26.48
-156.60	-131.76	-139.30	-99.94	-44.80	-30.86
-172.50	-185.06	-148.80	-119.45	-53.10	-46.75
-196.30	-194.69	-158.60	-135.55	-53.80	-52.09
-226.80	-223.43	-160.70	-171.05	-77.10	-54.56
-264.80	-292.99	-197.80	-182.52	-79.10	-60.69
-312.10	-310.47	-256.10	-233.17	-93.90	-65.93
		-355.60	-351.51	-99.20	-68.80
				-99.90	-85.99
				-111.00	-91.73
				-138.40	-102.51
				-139.30	-112.01
				-148.80	-113.88

Table 43 (cont'd).

H293		H294		Combined	
Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
				-156.60	-122.68
				-158.60	-123.77
				-160.70	-130.29
				-172.50	-132.76
				-196.30	-138.60
				-197.80	-162.13
				-226.80	-180.46
				-256.10	-186.75
				-264.80	-205.73
				-312.10	-273.17
				-355.60	-314.50

[H293] 1993 second harvest model
[H294] 1994 second harvest model
[Combined] combined 1993 and 1994 second harvest model
[Obs] observed difference (kg/ha)
[Pred] predicted difference (kg/ha)

APPENDIX I

Observed and predicted paired plot production differences for the high deer density area

Table 44. Observed and predicted paired plot production differences (kg/ha), in descending order (negative numbers represent production losses), between exclosed plots and plots open to foraging in the high deer density area for the 1993 harvest model, the 1994 harvest model, and the combined harvest model.

HD93		HD94		Combined	
Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
74.30	1.34	57.00	-38.40	74.30	54.17
41.70	-14.76	-94.00	-97.74	57.00	13.85
-70.40	-45.93	-123.50	-153.44	41.70	-9.10
-89.30	-46.03	-139.40	-205.72	-70.40	-48.70
-130.00	-99.54	-170.10	-210.00	-89.30	-104.35
-181.50	-167.76	-187.50	-230.61	-94.00	-108.39
-198.00	-224.68	-305.10	-241.60	-123.50	-135.71
-261.80	-263.59	-364.0	-243.31	-130.00	-170.64
-494.40	-476.69	-438.40	-396.32	-139.40	-173.66
-542.00	-513.74	-496.10	-443.95	-170.10	-185.25
				-181.50	-186.29
				-187.50	-231.19
				-198.00	-270.89
				-261.80	-283.62
				-305.10	-328.64
				-364.00	-332.19
				-438.40	-340.97
				-494.40	-374.77
				-496.10	-375.30
				-542.00	-520.85

HD93 1993 harvest model
HD94 1994 harvest model
Combined combined 1993 and 1994 harvest model
Obs observed
Pred predicted

APPENDIX J

Observed and predicted paired plot production differences for the low deer density area

Table 45. Observed and predicted red kidney bean production differences (kg/ha), in descending order (negative numbers represent production losses), between exclosed plots and plots open to foraging in the low deer density area for the 1993 harvest model, the 1994 harvest model, and for the combined harvest model.

LD93		LD94		Combined	
Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
508.70	479.01	410.70	397.23	508.70	514.70
252.60	29.94	354.70	358.40	410.70	507.69
183.30	-143.67	279.60	280.14	354.70	253.55
-99.20	-211.82	-293.70	-271.76	279.60	165.65
-166.60	-211.82	-498.20	-487.32	252.60	84.87
-245.30	-211.82	-601.10	-658.66	183.30	-69.68
-483.40	-211.82	-704.40	-670.44	-99.20	-141.80
-643.90	-211.82			-166.60	-224.51
				-245.30	-235.78
				-293.70	-245.43
				-483.40	-360.82
				-498.20	-393.92
				-601.10	-450.77
				-643.90	-511.88
				-704.40	-638.03

LD93 1993 harvest model
LD94 1994 harvest model
Combined combined 1993 and 1994 harvest model
Obs observed difference (kg/ha)
Pred predicted (kg/ha)

APPENDIX K

Observed and predicted percentages of browsed current annual growth twigs for tart cherry orchards

Table 46. Observed and predicted percent browsed current annual growth twigs in tart cherry orchards in northern lower Michigan, in descending order, in areas open to browsing for 1993, 1994, and the combined model.

1993		1994		Combined	
Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
19.46	19.39	19.11	18.74	19.46	16.51
18.87	19.05	9.45	7.27	19.11	16.51
18.86	18.72	8.77	4.97	18.87	15.88
1.94	1.96	0.69	4.19	18.86	15.88
		0.29	3.14	9.45	13.25
				8.77	13.25
				1.94	6.75
				0.69	1.15
				0.29	-1.75

[Combined] 1993 and 1994 combined model
[Obs] observed percentage of browsed current annual growth twigs
[Pred] predicted percentage of browsed current annual growth twigs

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