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The Roles of Heterogeneity and Scale in Mallard Nest Site Selection

By

Peter Joyce

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of Master of Natural Resources Management.

August 2001

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THE ROLES OF HETEROGENEITY AND SCALE IN

MALLARD NEST SITE SELECTION

BY

PETER JOYCE

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of

Manitoba in partial fulfillment of the requirement of the degree

of

MASTER OF NATURAL RESOURCES MANAGEMENT

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Abstract

Waterfowl use of tall, relatively homogeneous upland nesting cover established as part of the North American Waterfowl Management Plan has often been lower than predicted by computer planning tools. Little information exists regarding the influence of patchiness or the spatial scales at which mallards (*Anas platyrhynchos*) select nesting habitats. The present study addresses these questions at the level of the nest site, and provides new information to managers concerned with improving the productivity of nesting habitat for prairie waterfowl.

Data were collected in conjunction with Prairie Habitat Joint Venture Assessment research, near Minnedosa, Manitoba in 1998. A random sample of 64 mallard nests were chosen from all nests located on a 65 km^2 study area. Vegetation characteristics were measured within 4 x 4, 16 x 16, and 32 x 32 meter sample grids centered at each nest and at paired non-nest points. Nest site preferences were found to be scale dependent, and were most strongly expressed at fine scales (< 2 meters from the nest). Mallards strongly avoided very low cover heights and densities (e.g. VOR < 1), and preferred cover with high structural heterogeneity, a low to intermediate range of cover heights and densities (e.g. VOR 1 – 5), and diverse vegetation that included interspersed grasses, forbs and shrubs. At broader scales (e.g. 2 – 16 meters from the nest), mallards showed a preference for interspersed grasses, forbs and shrubs, avoided cropland and other habitats with low cover height and density (e.g. VOR < 2), and exhibited a weak preference for higher cover heights and densities (e.g. VOR 2 – 6). Overall mean visual obstruction was higher at nest sites than at non-nest sites at all scales.

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Observed habitat preferences suggest that management for nesting cover with an intermediate height and density, a high diversity and interspersion of grasses, forbs and shrubs, and fine scale structural heterogeneity may increase its attractiveness to nesting mallards. Incorporating scale dependent habitat preferences and heterogeneity into models of nest site selection may improve their predictive power and the efficacy of resulting management prescriptions. Further research is recommended to resolve uncertainties regarding the influences of concealment, heterogeneity and other cover characteristics on the attractiveness and productivity of various habitats.

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1.0 INTRODUCTION

1.1 Background

Diminishing waterfowl nesting habitat and declining duck populations in the prairies
precipitated the adoption of the North American Waterfowl Management Plan in 1986
(NAWMP; Anon. 1986). The primary objective of NAWMP is to restore duck
populations to levels recorded in the 1970s. Intensive and extensive programs have been
created to achieve this goal, most of them oriented toward improving duck nesting
success through the establishment and management of upland cover. However, nesting
use of these plots has been lower than anticipated (e.g. Klett *et al.* 1988, Clark and Nudds
1991, Devries *et al.* 1994, Sargeant 1996, McKinnon and Duncan 1999), suggesting that
our understanding of nest site selection behavior is not complete.

Computer modeling tools such as the Mallard Model (Johnson *et al.* 1987) are used to
guide NAWMP management efforts. Nest site selection is an important component of
the model, since the potential number of ducks produced in a given habitat is dependent
on the number of nests initiated there. The probability of nesting in a habitat is the
product of its attractiveness and the availability of the habitat in the landscape (Johnson *et
al.* 1987). Based on the preference of mallards (*Anas platyrhynchos*) to nest in tall dense
cover (Kirsch *et al.* 1978), habitat attractiveness is calculated from mean visual
obstruction values of vegetation (Robel *et al.* 1970, Johnson *et al.* 1987). Because mean
visual obstruction is a measure of the central tendency of vegetation height and density,
the Mallard Model inherently assumes that cover attractiveness can be estimated without

considering spatial variability. However, spatial variability in height-density measurements of vegetation has been associated with the capacity of grassland habitats to support passerines (Wiens 1974, Hoekman 1999) and galliformes (Cannon and Knopf 1981, Messmer 1985). A better understanding of the importance of within-patch spatial variability in mallard nest site selection would provide useful direction for waterfowl habitat management.

In addition to spatial variability, scale considerations are critical to studies of animal–habitat relationships (Wiens 1989, Turner and Gardner 1991, Orians and Wittenberger 1991, Levin 1992, Pribil and Picman 1997). Johnson (1980) suggests habitat selection in mallards may be a hierarchical process occurring over a range of scales. If the habitat is studied at a different scale than perceived by the study animal, important patterns may be missed or misinterpreted.

Little information exists on the influence of patchiness and the spatial scales at which mallards select nesting habitats (but see Hoekman 1999). The present study addresses these questions at the level of the nest site, and should provide additional information to assist habitat managers concerned with improving the productivity of prairie landscapes for waterfowl.

1.2 Issue Statement

Waterfowl managers face many uncertainties when delivering programs designed to increase duck production. Use of managed habitat by nesting waterfowl often has been

lower than expected, suggesting our understanding of nest site selection behavior may be incomplete. To better direct current and future management decisions, more information is needed about the attractiveness and associated productivity of managed habitats for breeding waterfowl, and the scales at which these factors are most important.

1.3 Objectives

The objectives of this study are:

I.   to determine if nest site selection is related to visual obstruction of nesting cover;

II.   to determine if spatial variability or patchiness of nesting cover is related to nest site selection, and;

III.   to determine spatial scales relevant to measures of nesting habitat for mallards.

1.4 Scope and Justification

On-going research, most notably the Prairie Habitat Joint Venture Assessment, will improve understanding of the effects of broad scale landscape settings and spatial factors in nest site selection and habitat productivity (Howerter, *pers. comm.*). While this work addresses higher order, "macro-scale" habitat selection phenomena (e.g. at the level of geographic landscapes of circa 65 km), the present study was confined to examining low order, "micro-scale" selection behavior at the level of the nest site.

Information derived from this study has several practical implications for habitat restoration programs. New information will be gained regarding habitat heterogeneity

and its effects on nest site selection by mallards. This could be used to improve the predictive power of management planning tools such as the Mallard Model. The model does not presently incorporate spatial variation into measures of habitat attractiveness, even though variation in cover height and density have been shown to increase the capacity of grassland habitats to support other bird species. Also, understanding of spatial scales at which female mallards select nest sites will be improved, and consequently, the most appropriate scales at which to measure and manage habitat will be determined.

The importance of spatial variation as a component of habitat attractiveness is valuable information for managers involved in NAWMP and other restoration programs. The results of the study help to identify appropriate cover heterogeneity "targets" for waterfowl managers.

1.5 Research Delimitations

The present study addresses questions related to the phenomenon of nest site selection in mallards. Its conclusions may not be applicable to other species. Patterns of habitat use vary with species (e.g. Kaminski and Weller 1992, Hoekman 1999), therefore the factors that influence habitat selection and scales at which these factors are important also may vary among species.

If mallard nest site selection is a hierarchical process (Johnson 1980), it should be studied hierarchically to identify cross-scale patterns. Observed patterns of habitat use may be

influenced by the scale of investigation and by temporal and spatial variation in the many factors that affect selection at each level of habitat (Wiens 1985).

The habitat selection processes examined in this study were probably influenced and affected by higher order selection processes, but these were beyond its scope. Therefore important factors and scales identified here may be more or less significant in other landscapes because of differences in the spatial and temporal arrangement of these higher scale factors.

The results also have been affected by the measures of heterogeneity chosen, the pattern and scale of variation in these variables, and the scale or "intensity" at which they are sampled. With only an incomplete understanding of the factors most important for mallard nest site selection and the scales at which mallards may perceive them, it was difficult to determine *a priori* if the variables chosen and the scales at which they were measured were appropriate.

2.0 LITERATURE REVIEW

2.1 Mallard Nest Site Selection and Habitat Preferences

2.1.1 Definitions of Habitat Use and Selection

As summarized by Kaminski and Weller (1992), the simplest and most common measure of habitat use by an individual or species is occurrence. A habitat correlation (or association) exists when an animal's presence or absence varies, either directly or inversely, with the presence or abundance of environmental components (Wiens 1976). However, habitat correlation cannot be construed as habitat selection. Habitat selection occurs when animals exercise a choice among available habitats, instead of differentially occupying them as a consequence of extrinsic factors such as predation, competition, population density, and/or environmental variations (Wiens 1976; 1977; 1985). However, in most field studies, controlling these extrinsic factors is generally impractical, and habitat selection is inferred when habitats are used disproportionately to their estimated availabilities (Johnson 1980), or when utilized resources differ statistically from unused or randomly selected areas. A number of statistical procedures are used to test between measures of habitat use and habitat availability (e.g. Manly *et al.* 1993), but none seems best for all applications (Alldredge and Ratti 1986).

2.1.2 Issues of Scale in Habitat Selection

Considering scale is very important in studies of the relationship of an animal to its habitat (Wiens 1989, Turner and Gardner 1991, Orians and Wittenberger 1991, Levin

1992). If the habitat is studied at a different scale than that perceived by the study animal, important patterns may be missed or misinterpreted.

Habitat selection in migratory birds may be envisioned as a hierarchical process from a macro- to micro-habitat scale (Johnson 1980). For example, female mallards may make a "first order" selection of a geographic/physiographic landscape, next a "second order" selection of an upland or wetland system and class (e.g., palustrine, emergent marsh [Cowardin *et al.* 1979]) within the landscape, and finally a "third order" selection of a nesting site within an upland or wetland (Wiens 1973, Johnson 1980). Ideally, habitat selection should be studied hierarchically to identify cross scale patterns, because observed patterns in habitat use can be influenced by scale of investigation as well as by temporal and spatial variation in the many factors that affect selection at each level of habitat (Wiens 1985).

2.1.3 Habitat Use and Nest Sites of Breeding Mallards

Bellrose (1979) and Johnson and Grier (1988) summarized data on the distribution of breeding dabblers in North American landscapes. Dabbler use of mixed prairie, parkland, delta and Alaskan taiga and tundra was found to be disproportionate to the availability of these landscapes. Use was highest in the parkland and mixed-prairie, implicating the importance of these landscapes to continental dabbler populations. The importance of the prairie-parkland region to North American ducks is corroborated by Hochbaum (1983) and Wishart *et al.* (1983).

Within landscapes, breeding dabblers use some wetland types more than others, but often in proportion to their availability. In the Canadian prairie-parkland region, shallow basin wetlands represent the principal aquatic habitat used by breeding dabbling ducks (Kaminski and Weller 1992). At the level of the wetland-upland complex, habitat use by breeding mallards and other dabbling ducks has been related to several factors, as reviewed by Kaminski and Weller (1992): (1) wetland type (Stewart and Kantrud 1973, 1974, Kantrud and Stewart 1977); (2) diversity of the aquatic and terrestrial habitat complex (e.g. Flake 1978, Kantrud 1986); (3) wetland abundance (Johnson and Grier 1988, but see Johnson and Shaffer 1987), annual conditions (e.g. Kaminski and Gluesing 1987), size (e.g. Brown and Dinsmore 1986, 1988), and shoreline complexity (Kaminski and Prince 1984); and (4) aquatic invertebrate abundance (Murkin and Kadlec 1986).

"Third order" selection of nest sites has been studied extensively. Mallards are primarily upland nesters, although they may also select nest sites on islands (Duebbert et al. 1983), artificial nesting structures such as nest tunnels (Eskowich et al. 1998, Emery et al. 1997), or emergent vegetation (Krapu et al. 1979, Arnold et al. 1993). Choice of upland nest sites has been related to availability, density and height of nesting cover more than to plant species (Kirsch et al. 1978); to nest site security from predators (e.g. Klett et al. 1988, Greenwood et al. 1987, Ball et al. 1995)); to proximity of wetlands (Bellrose 1979, Livezey 1981); and to the presence of other nesting species (e.g. Giroux 1981).

Early nesting mallards usually require residual or perennial cover for nest establishment (Kirsch et al. 1978). Most studies indicate that dabbler nest densities and nesting success

increase with increasing availability of undisturbed, dense grass, forbs, and shrubs (e.g. Duebbert and Lokemoen 1976, Kirsch *et al.* 1978). However, the use of dense nesting cover by mallards and other upland nesting ducks has at times been low (Clark and Nudds 1991, Devries *et al.* 1994, McKinnon and Duncan 1999), suggesting our understanding of the relationships between nest site selection and proximate habitat factors is incomplete.

2.2   Heterogeneity and Nesting Habitat Selection in Birds

Most environments studied by ecologists are spatially heterogeneous, that is, more than a single element is present, and they are usually spatially complex (Wiens 1995). Heterogeneity or patchiness in nesting vegetation produces mosaics of potential nesting habitat, defined by the spatial distribution of different plant species, cover heights and densities (Prose 1992). Heterogeneity in vegetation height and density has been associated with the capacity of grassland habitats to support breeding songbirds (Wiens 1974), lesser prairie chickens (Cannon and Knopf 1981), and sharp-tailed grouse (Messmer 1985). Although nesting use by mallards has been related to average cover height and density (e.g. Kirsch *et al.* 1978), the influence of cover heterogeneity has received little attention in the literature. Since patterns of variation are scale dependent, effective studies of heterogeneity must focus on those scales that have meaning for the animals being studied (Wiens 1989, Prose 1992).

2.3   Habitat Programs and Goals of the North American Waterfowl Management Plan (NAWMP) and PHJV Assessment

The North American Waterfowl Management Plan (NAWMP) is a 15 year agreement, originally signed in 1986 by Canada and the United States, and in 1988 by Mexico (NAWMP, Anon. 1994). Its primary goal is to increase breeding waterfowl populations to levels characteristic of the mid-1970s. Low average nesting success of dabbling ducks, more than any other factor, is believed to limit waterfowl production in prairie Canada (Greenwood *et al.* 1997). Intensive and extensive programs have therefore been created to increase duck breeding success, most of them oriented toward the establishment and management of upland cover.

The NAWMP is implemented in the Canadian prairie pothole region by the Prairie Habitat Joint Venture (PHJV), a consortium of co-operating government and non-government agencies. The goal for the PHJV is to secure, enhance and protect 1.5 million Ha (3.6 million acres) of waterfowl habitat in the prairie provinces of Canada. Between 1986 and 1995, PHJV partners secured 311,603 Ha, or 21 % of this goal, at a cost of $1.77 Million. Of these, 124,580 Ha have been enhanced and 251,537 Ha are under active management as wildlife habitat (Andrews 1996).

To help accomplish Plan goals, NAWMP partners are committed to a rigorous biological evaluation of habitat programs through programs such as the PHJV Assessment (Emery *et al.* 1997). As stated by Clark and Diamond (1993) considerable uncertainty remains regarding: (i) which of several intensive management techniques is most effective for

ducks and other wildlife, (ii) whether intensive programs are more effective than extensive ones, and (iii) whether current intensive programs could be made more effective. The major objectives of the PHJV Assessment address these questions, and seek to test the assumptions and parameters of the Mallard Model, a computer modeling tool that was used to plan PHJV habitat programs.

2.4   The Mallard Model

Computer modeling tools such as the Mallard Model (Johnson *et al.* 1987, 1988) are used to guide NAWMP management efforts. The model incorporates several environmental phenomena and biological relations that affect mallard recruitment. Major inputs include arrival of mallards in spring, daily survival of adult females, initiation of nests, selection of nest sites, survival of nests until hatching, and survival of broods until fledging. The model allows hypothetical cover types to "compete" for nesting hens, and predicts the effect of different habitat configurations on mallard recruitment. Nest site selection is an important component of the model, since the potential number of ducks produced in a given habitat is dependent on the number of nests initiated there. The probability of nesting in a habitat is the product of its attractiveness and the availability of the habitat (Johnson *et al.* 1987). Based on the preference of mallards to nest in tall dense cover (Kirsch *et al.* 1978), the model estimates habitat attractiveness from mean visual obstruction values of vegetation (Robel *et al.* 1970, Johnson *et al.* 1987). Because mean visual obstruction is a measure of central tendency, the model inherently assumes that cover attractiveness can be estimated without considering spatial variability. However, as discussed above, spatial variability in height-density measurements of vegetation has

been associated with the capacity of grassland habitats to support other birds. It appears the model underestimates the importance of within-patch spatial variability in mallard nest site selection.

2.5 Methods

Methods for sampling spatial pattern: Past studies of habitat variation in the vicinity of upland bird nests have sampled two-dimensional space using line transects (e.g. Prose 1992). This method assumes that the habitat variable under study varies independently of the direction taken from the nest and that the two-dimensional space surrounding the point of interest can be represented by sampling along a one-dimensional line. Although line transects are useful for randomly sampling the scale and intensity of spatial patterns in plant communities (e.g. Hill 1973), most natural phenomena vary dependent on the direction taken from a point of interest such as a nest (Jongman *et al.* 1995). With line transect techniques, space close to the nest also is sampled more intensively per unit area than space further away from the nest, and confidence levels decline as analysis is applied at coarser scales. Finally, line transect techniques limit the kinds of spatial statistics which may be applied to the data. For these reasons, a relatively rigorous scheme of grid sampling at nest and random sites was undertaken.

Measures of vegetation height and density: A variety of devices have been used for measuring the horizontal visual obstruction caused by grassland vegetation. For example, Nudds (1977) devised a 2.5 m x 30.48 centimeter "vegetation profile board" to assess visual obstruction of vegetation in five 0.5-m vertical intervals above the ground. Horizontal cover is assessed by viewing the board from 15 m in a randomly chosen

direction, and scoring obstruction in each interval based on the percent concealment. Griffith and Youtie (1988) used a similar scoring system to measure visual obstruction of a graduated pole with comparable results. The time required for scoring (8 hours per 100-200 readings cited by Higgins *et al.* 1996) is a serious drawback to these methods. Robel *et al.* (1970) devised another system in which a pole-shaped cover board (3 x 150 cm) marked in 10 cm intervals is read from a standard distance (4 m) and height (1 m). The height of total visual obscurity is then recorded. Visual obstruction readings were shown to be an effective method for estimating vegetation biomass in tall grasses. However, in short-grass prairie or other sparse vegetation, poles as cover boards may not provide useful information (Higgins *et al.* 1996).

Plant height can be estimated with a high degree of precision in many grasslands, and correlates well with other structural attributes of herbage (Higgins *et al.* 1996). For example, Higgins and Barker (1982) reported that maximum area-height explained 63% of the foliage density values that were taken concurrently with a Robel pole in waterfowl nesting cover. Herbage height can refer to the tallest portion of a plant, effective height (the upper limit of vegetation leafiness), or area-height of herbage below a specified area such as a 30-cm-diameter plastic disc (Higgins *et al.* 1996).

Density, horizontal position and height of grassland vegetation on sharp-tailed grouse display grounds was estimated by Twedt (1974) using a 1m x 1m cover board gridded with dots at 5-centimeter horizontal and vertical intervals. Height and density was

estimated from the number of dots intercepted in photographs of 0.1m x 1.0m vegetation transects using the cover board as a backdrop.

The objectives and design of the present study dictated that visual obscurity of vegetation be characterized at a large number of sampling locations and sites (133 observations per site x 128 sites) over a relatively short field season. Although cover boards designed to describe the vertical distribution of obstructing vegetation probably provide more detailed information about vegetation structure, the time required for scoring made these methods impractical. A combination of visual obstruction (Robel 1970) and vegetation area-height (Higgins *et al.* 1996) measurements were therefore used to rapidly estimate vegetation height and density characteristics.

3.0 METHODS

3.1 Study Area

Data were collected in conjunction with PHJV Assessment activities on a 64-km^2 (25-mi^2) study area centered approximately 8 km south of Minnedosa, Manitoba (55°16'N, 99°50'W). As summarized by Arnold and Fritzell (1987), the study area lies on the Newdale glacial moraine in the aspen parkland region of prairie Canada. It supports a diverse system of Palustrine Persistent Emergent Wetlands (Cowardin *et al.* 1979), and is an important area for continental waterfowl production (Bellrose 1979). Most uplands are intensively farmed, primarily for cereals (wheat, barley) and oilseeds (flax, canola), although various habitat management treatments have been implemented in the area since the NAWMP began in 1986. A variety of habitat types are available to nesting mallards, including grassland, hayland, planted cover, cropland, woodland, scrubland, and wetland (see detailed descriptions of habitat classes in Table 3-1). The Aspen Parkland Ecoregion and the Minnedosa area are described in additional detail by Bird (1961) and Kiel *et al.* (1972), respectively.

3.2 Sample Design

Selection of Nest Sites

A sample of 64 mallard nests in planted cover, grassland and shrubland were randomly chosen for study over the course of the 1998 nesting season from nests located by the PHJV Assessment crew. All available planted cover and a random sample of native/naturalized cover (excluding woodlands) was systematically searched using

standard methods (Higgins *et al.* 1969, Emery *et al.* 1997). A representative proportion of the experimental nests were selected from grassland, shrubland and planted nesting cover according to the relative number of radio-marked female mallards determined to be nesting in these habitats by concurrent PHJV Assessment research on the study site.

Selection of Paired Non-nest Sites

Within two days of nest site sampling, one paired non-nest site was selected and measured within the same 160 acre (62.5 Ha) quarter-section as the nest site. For nest sites located in planted cover, non-nest sites were randomly chosen within planted cover (Table 3-1) in the same 160 acre (62.5 Ha) quarter-section using a 30 meter x 30 meter dot grid and 1:10 000 scale air photo maps. Shrub patches were not easily detected on the study area maps and are commonly lumped together with grassland cover in waterfowl nesting habitat studies (e.g. Greenwood *et al.* 1995). Therefore, non-nest sites paired with nests located in grassland and shrubland were randomly chosen within potential grassland or shrubland areas in the same quarter section. In all cases, once at the selected random map location, the investigator traveled a random distance (0 – 30 m) and direction (0 – 360°) within the cover patch to select the final point of measurement. Non-nest sample grids then were centered on this point, and vegetation measurements were taken as described for nest sites. If a mallard nest was discovered within the outer 32 x 32 meter boundary of a non-use site during sampling, the site was discarded and another was chosen.

Layout of sampling grids

Three nested vegetation sampling grids were centered on each nest and non-nest site (Figure 3.1), and consisted of: (1) a 4 x 4 meter matrix sampled at 4 x 0.5 meter intervals, (2) a 16 x 16 meter matrix sampled at 4 x 1 meter intervals, and (3) a 32 x 32 meter matrix sampled at 4 x 4 meter intervals. Corners of the 4 x 4 m, 16 x 16 m and 32 x 32 meter grids were located 2.8 meters, 11.3 meters and 22.6 meters, respectively, along intercardinal compass bearings taken from the nest, and were marked with metal conduit poles. Intervals were then measured and flagged every 4 meters along northern and southern grid boundaries.

Vegetation Sampling

The following information was recorded at all points in the sampling grids:

- PHJV habitat cover class (Table 3-1).

- Vegetation area-height, estimated using a 30 cm Plexiglas disc (as outlined in Higgins *et al.* 1996).

- Vegetation class (Table 3-2). At each sample point, the Plexiglas area-disc was held at the level of the observer's chest, the plants beneath it were viewed through the disc, and those vegetation classes that comprised more than 30% of the disc area were recorded in decreasing order of importance.

- Visual obstruction of vegetation (VOR), estimated using a 3 x 150 cm Robel pole (Robel *et al.* 1970). To minimize trampling of the vegetation, the observer measured visual obstruction from a location 4 meters west of each grid location, and grid transects were systematically sampled in a north to south/ south to north pattern

starting at the north-west 32 x 32 meter grid corner, and ending at the south-east 32 x 32 meter grid corner.

- Within 4 x 4 meter grids, cover was also sketch-mapped, percent cover was estimated by vegetation class, and sites were photographed at an oblique angle from the observer's eye level.

The measures used were designed to estimate the characteristics of grassland vegetation, and are not well-suited to woodlands and some wetlands (Higgins *et al.* 1996, Nudds 1977). Where grid sample points fell in flooded or wooded areas, only the PHJV cover class was recorded. Flooded areas were defined for this purpose as areas where standing water was present, and woodlands were defined as areas dominated by woody vegetation greater than 6 meters in height having greater than 30 % areal cover.

To minimize the effect of temporal changes in vegetation structure during the interval between nest site selection, discovery of the nest, and data collection at nest sites, sampling at nest sites was conducted as soon after nest initiation as possible, but in all cases, no later than twenty days after nest initiation. The stage of incubation was determined by candling several eggs from each nest (Weller 1956).

Permanent Transects

To characterize temporal changes in vegetation over the duration of the study, eleven randomly selected 32 meter permanent transects were established in planted and grassland cover within the study area. A random sample of 6 quarter sections containing

planted cover and 5 quarter sections containing grassland and shrub cover was selected, and transect end points were identified following the protocol for choosing non-use sites. Whenever possible, transects were established along a northern bearing from the randomly selected end point. In some cases (most grassland transects) the configuration of the cover patch prevented this, and the transect was oriented along a randomly chosen bearing ($0 - 360°$) so that all sample points fell in the appropriate cover type. Following transect establishment, VOR, vegetation height and vegetation class were measured at 1 meter intervals once weekly for the duration of the study.

3.3 Data Analysis

Project objectives and null hypotheses were addressed at the 4m x 4m, 16m x 16m, and 32m x 32m scales as follows:

Objective I: Relationship of nest site selection to visual obstruction of nesting cover

Null hypothesis: *Nest site locations selected by mallards are distributed randomly relative to the visual obstruction of available nesting cover.*

The analysis first considered whether mean visual obstruction readings (VORs) collected about nest sites differed from those at non-nest sites. A paired t-test of mean VOR was performed at each of the three sampling scales. Tests were one-tailed because the alternate hypothesis was directional (i.e., that mean VOR would be greater in nest sites than in non-nest sites; Kirsch *et al.* 1978).

Habitat preferences also may be established by comparing the distribution of vegetation characteristics at nest sites with the distribution of those characteristics at available sites (Pribil and Picman 1997, Wiens 1985) At each scale, and for nest and non-nest plot centres, the distribution of "available" VORs measured in non-nest sites was compared to the distribution of "used" VORs measured in nest sites. Chi-square tests of independence were performed to determine if the observed differences in these distributions were statistically significant. Finally, the difference between the relative occurrence of used and available VORs at each scale was calculated as an index of attractiveness or habitat preference for various cover heights and densities.

Objective II: Relationship of nest site selection to spatial variability (patchiness) of nesting cover

Null Hypothesis: *Nest site locations selected by mallards are distributed randomly relative to nesting cover heterogeneity.*

The relationship of heterogeneity to nest site selection was examined in three ways:

1. Aspatial analysis of continuous variables: Exploratory analysis indicated that mean VOR and vegetation height significantly differed between nest and non-nest sites at some scales. Since this made direct comparisons of sample variances invalid, paired t-tests of Coefficient of Variation (Bart and Notz 1996) of VOR and vegetation height were conducted to test relative variation in nest and non-nest sites.

2. Aspatial analysis of categorical variables: Cover composition of nest and non-nest sites was estimated at each scale of measurement from the PHJV habitat cover and vegetation class data. Paired t-tests were performed to determine if the relative amount of each vegetation and cover type differed in nest and non-nest sites, and a Chi-square test for independence was performed to compare the overall vegetation and cover distributions in nest and non-nest sites. The Shannon-Weaver Diversity Index (Smith 1996) was then calculated for each nest and non-nest site, and paired t-tests were performed to determine if vegetation class diversity (VEG-DIV) and PHJV cover class diversity (CL-DIV) differed between nest and non-nest sites at the scales studied.

3. Spatial analysis of data: Three methods were used to estimate and compare spatial patterns of variation in the data.

First, mean VOR was calculated for each individual sample point across all nest and non-nest sites, and surface charts were created to show "average" patterns in the VOR data at each scale of measurement. Examination of VOR surface charts suggested that at the 16 x 16 and 4 x 4 meter scales, mean VOR was greater to the south and west than it was to the north and east of nest sites. To confirm if mean VOR significantly varied by direction around nest sites, mean VOR was calculated for sample points in the north and south halves of 4 x 4 and 16 x 16 meter nest sites, and for an 8 x 8 meter subset of sample points extracted from the 16 x 16 meter nest data. The 8 x 8 meter data set consisted of VORs collected from points D12-20, E12-20, and F12-20 (Figure 3.1) in a grid pattern extending 4 meters out from the nest. Mean VOR was also calculated for sample points

in the east and west halves of the 16 x 16 meter and "8 x 8 meter subset" data. Paired one-tailed t-tests were conducted to determine if mean VOR west of nest sites was greater than mean VOR east of nest sites, and if mean VOR south of nest sites was greater than mean VOR north of nest sites.

Next, edge analysis was conducted using methods adapted from Baxter and Wolfe (1972) and Heinen and Cross (1983). Vegetation class data were transcribed into a matrix of cells according to the spatial arrangement of sample points within 16 x 16 and 32 x 32 meter sites, such that the value at each sample point was represented by one cell in the matrix. For each 4 x 4 meter site, a similar matrix was created by transcribing data from vegetation maps using a clear acetate 5 x 5 grid overlay. "Edges" were counted where adjoining cell values differed. An edge score was generated at each scale, and a paired t-test was conducted to determine if the edge score differed between nest and non-nest sites.

Finally, analysis was conducted to test for spatial autocorrelation in the VOR data. As suggested by Legendre and Legendre (1998), VOR values collected systematically over the sample grids form a surface suited to spatial pattern analysis. Spatial autocorrelation is a measure of the systematic pattern of variation in a variable in space, and serves as a useful tool to quantify spatial heterogeneity (Legendre and Legendre 1998). The Moran's I Coefficient (Upton and Fingleton 1985, Legendre and Legendre 1998) was used in this study as an index of spatial autocorrelation in the VOR data. The 32 x 32 meter and 16 x 16 meter site data were transcribed into 9 x 8 and 4 x 17 matrices,

respectively, and spatial analysis software developed by Kenkel (2000) was used to estimate "average" Moran's I values for each surface. The analysis was repeated using two different Euclidean Distance (ED) metrics, 1/ED and $1/ED^2$. Analysis using the $1/ED^2$ metric weighted the influence of adjacent values more heavily than the 1/ED metric. Two-tailed paired t-tests were then conducted to determine if Moran's I values at nest and non-nest sites differed.

Except where otherwise noted, tests of aspatial and spatial heterogeneity measures were one-tailed because the alternate hypothesis was directional (i.e., that nest sites are more heterogeneous than non-nest sites; Wiens 1985, Hoekman 1999).

Objective III: Spatial scales relevant to mallard nest site selection.

Except where noted, the above analyses were performed at 4 x 4, 16 x 16 and 32 x 32 meter scales, and the significance of observed differences in nest and non-nest sites was compared at each scale of analysis.

Analysis of permanent transect data

Mean VOR, mean vegetation height, CV of VOR, CV of vegetation height and Shannon-Weaver vegetation class diversity were calculated for each permanent transect and sampling date. To characterize temporal changes in vegetation over the duration of the

study, mean values were pooled for planted, grassland and all transects for each variable

and sampling date, and the data were plotted over time.

Table 3-1. PHJV Habitat Cover Classes used in the present study (after Emery *et al.* 1997).

Code	Description
G	**Grassland.** Native or naturalized areas vegetated with various mixtures of grasses, forbs, and short woody species. Introduced grasses may have also been present. This situation is in contrast to classes hayland and planted cover where the area may have been plowed and planted to grasses or legumes in order to establish grass/legume forage. In the present study, grasslands were predominantly idle but in some cases had been burned or hayed during the previous spring or fall.
H	**Hayland.** Areas that have been plowed and seeded to mixtures of grasses and legumes for forage production and that are hayed annually. In many cases this type is represented by alfalfa (*Medicago sativa*) hay on private land.
P	**Planted cover.** Planted cover includes a number of mixtures of grasses and legumes planted for wildlife cover or soil conservation. Species include introduced cool season grasses, legumes, and various mixes of native cool season grasses. Planted cover cannot be distinguished from planted introduced grasses that are in a non-use condition; these areas are grouped with planted cover.
C	**Cropland.** Areas that are tilled and planted to grain or row crops or that are plowed and left fallow or contain crop residue.
F	**Woodland.** Areas with woody plants (trees or tall shrubs) >6m in height having an areal cover >30%.
S	**Scrubland.** Areas of shrubs 0.5 to 6m tall having an areal cover of >30%. If areal shrub cover is <30%, the habitat should be classified as grasslands.
W	**Wetland.** All areas regardless of size defined as wetland according to definitions in Cowardin *et al.* (1979).
O	**Other.** Includes all habitats that don't fit into any of the above habitat codes.

Table 3-2. Vegetation class categories and codes used in the present study (after Emery *et al.* 1997).

Code	Description
B	**Bare.** Denotes areas with <30% areal plant cover.
G	**Grass.** Denotes areas dominated by introduced or native upland graminoids.
F	**Forbs.** Denotes areas dominated by upland forbs such as alfalfa (*Medicago sativa*) and sweet clover (*Melilotus* spp.) and other non-woody broad-leaved plants.
S	**Shrub.** Denotes areas dominated by shrub species <6m in height.
H	**Hydrophytes.** Denotes areas dominated by hydrophytes. A hydrophyte is any species listed as an "obligate wetland species" on the National List of Plant Species that Occur in Wetlands (Reed 1988).
W	**Standing water.** Denotes areas of standing water (may be open water or dominated by hydrophytes) where vegetation data were not collected.
A	**Annual crop.** Denotes areas dominated by annual crops.
T	**Trees.** Denotes areas dominated by woody vegetation >6m in height and having >30% areal cover.
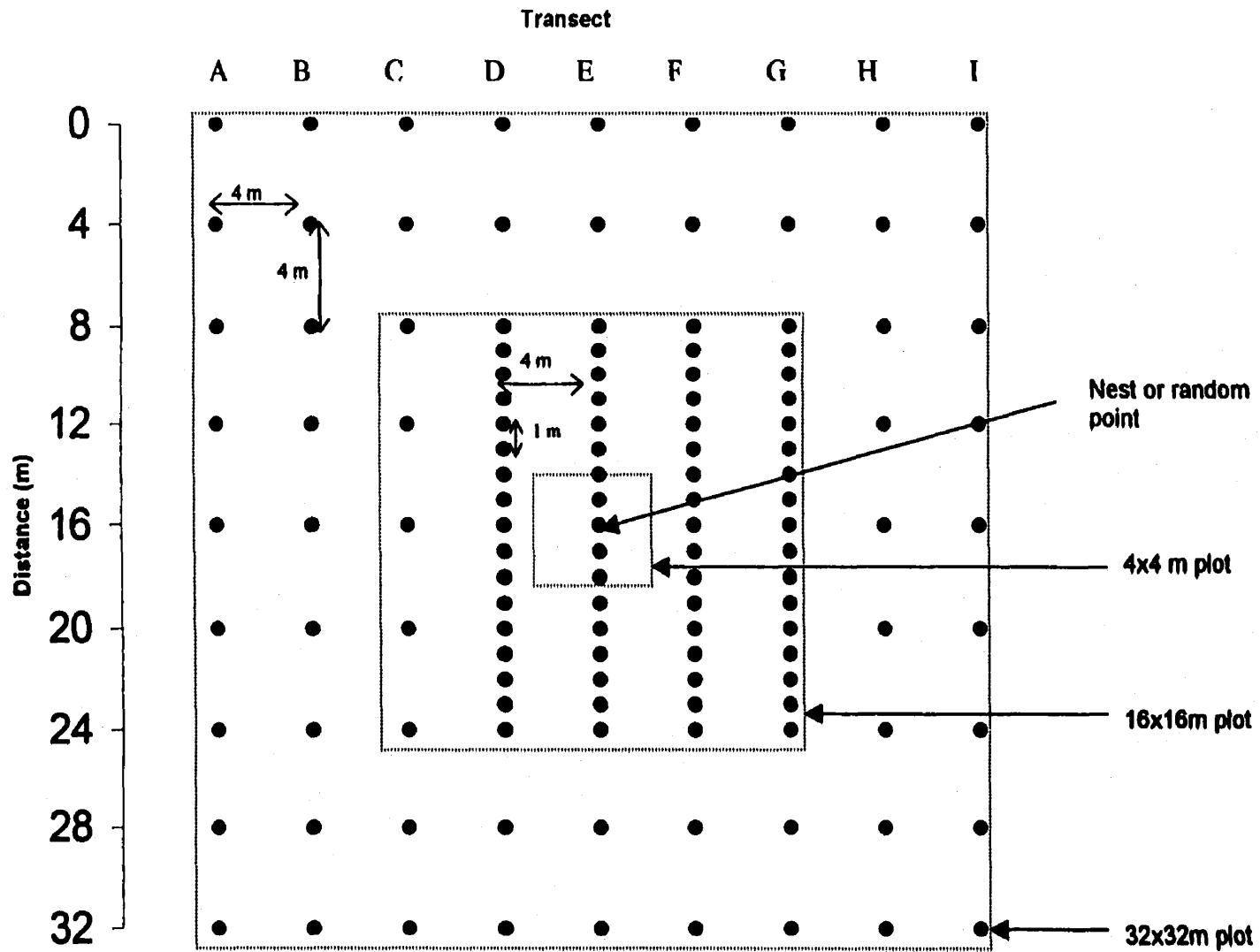
Figure 3.1: Layout of vegetation sampling points used at nest and non-nest sites

4.0 RESULTS

4.1 Relationship of nest site selection to visual obstruction of nesting cover

4.1.1 Mean visual obstruction at nest and non-nest sites

Paired t-tests were conducted to determine if mean VOR differed in nest and non-nest sites. Mean visual obstruction readings (VOR) were greater in nest sites than in non-nest sites at the 4 x 4 (t=2.55, P=0.007, 64 d.f), 16 x 16 (t=3.60, P<0.001, 63 d.f), and 32 x 32 meter (t=3.34, P=0.001, 63 d.f.) scales. Mean VOR results are summarized in Figure 4.1 and Table 4.1.

Results were similar for mean vegetation height and VOR in nest and non-nest sites. Mean vegetation height (Figure 4.2) was greater in nest sites than in non-nest sites at the 4 x 4 meter (t=1.67, P=0.050, 63 d.f.), 16 x 16 meter (t=2.32, P=0.012, 63 d.f.) and 32 x 32 meter (t=1.63, P=0.054, 63 d.f.) scales, although the difference between nest and non-nest sites was not statistically significant at the 32 x 32 meter scale when $\alpha = 0.05$. Paired t-test results for mean vegetation height in nest and non-nest sites are summarized in Table 4.1.

4.1.2 Distribution of visual obstruction data at nest and non-nest sites

The relative frequency distributions of VORs measured in 4 x 4, 16 x 16, and 32 x 32 meter sampling grids and at nest and non-nest grid centres are presented in Figure 4.3. Chi-square tests for independence confirmed that nest and non-nest VOR distributions differed at 4 x 4 ($\chi^2 = 48.1$, P<0.001), 16 x 16 ($\chi^2 = 171.9$, P <0.001), and 32 x 32 meter

$(\chi^2 = 101.8, P<0.001)$ scales. Differences in the relative occurrence of used (nest) and available (non-nest) cover heights and densities are presented in Figure 4.4. Negative values correspond to cover heights and densities that were avoided (used less than they were available), positive values correspond to cover heights and densities that were preferred (used more than they were available) and neutral values correspond to cover heights and densities that were neither preferred nor avoided (e.g. use is approximately equal to availability).

At broader scales (32x32 and 16x16 meter), mallards showed a slight preference for an intermediate range of vegetation densities (e.g. VOR 2-6), avoided cover of low VOR (e.g. 0-2), and neither preferred nor avoided very dense cover (e.g. VOR > 6). At fine scales (4x4 meter sites), very low cover heights and densities were more strongly avoided, low densities (VORs =1-2) were neither preferred nor avoided, intermediate densities (2-5) were strongly to moderately preferred, and high densities were either weakly avoided or neither preferred nor avoided. At the level of the nest site, very low cover heights and densities were almost completely avoided, a low to intermediate range (VORs 1-5) was rather strongly preferred, and vegetation with VOR>5 was either avoided or neither preferred nor avoided. As scale decreased, preferences were more pronounced, very low cover heights and densities were more strongly avoided, fairly strong preferences emerged for intermediate cover heights and densities between VOR 1-5, and very tall, dense cover was less attractive.

4.2 Relationship of heterogeneity and scale to nest site selection

4.2.1 Coefficient of variation of visual obstruction

Mean coefficient of variation (CV) of VOR was not significantly different in nest and non-nest sites at either the 4 x 4 meter (t = - 0.982, P = 0.165, 63 d.f.), 16 x 16 meter (t = 0.677, P= 0.677, 63 df) or 32 x 32 meter scale (t = -0.502, P = 0.309, 63 d.f.). CV of VOR results are presented in Figure 4.5 and Table 4.2.

4.2.2 Coefficient of variation of vegetation height

Mean CV of vegetation height in nest and non-nest sites is compared across 4 x 4, 16 x 16 and 32 x 32 meter scales in Figure 4.6 and Table 4.2. CV of vegetation height was significantly greater in nest than in non-nest sites at the 4 x 4 meter scale (t = 1.793, P = 0.039, 63 d.f.), but did not differ significantly in nest and non-nest sites at the 16 x 16 (t = -0.250, P = 0.401, 63 d.f.) and 32 x 32 (t = - 0.410, P = 0.341, 63 d.f.) meter scales.

4.2.3 PHJV habitat class composition

PHJV habitat class composition of 4 x 4, 16 x 16 and 32 x 32 meter nest and non-nest sites is shown in Figure 4.7 and Table 4.3. Chi-square tests for independence indicated cover composition at nest sites differed significantly from non- nest sites at the 32 x 32 (χ^2 = 203.5, P<0.001), 16 x 16 (χ^2 = 276.6, P < 0.001) and 4 x 4 (χ^2 = 69.6, P < 0.001) meter scales. At the 4 x 4 meter scale there was significantly less grassland (t = -2.81, P = 0.003, 63 d.f.), and more shrubland (t = 2.30, P = 0.012, 63 d.f.) in nest sites than in non-nest sites. At the 16 x16 meter scale, there was significantly more shrubland (t = 2.34, P = 0.011, 63 d.f.), less cropland (t = -1.71, P = 0.046, 63 d.f.), more woodland (t =

1.79, P = 0.038, 63 d.f.), and more other areas (t = 2.09, P = 0.020, 63 d.f.), such as roads, in nest sites than in non-nest sites. At the 32 x 32 meter scale, there was significantly less cropland (t = -1.94, P = 0.028, 63 d.f.) and more other areas (t = 3.25, P < 0.001, 63 d.f.) in nest sites than in non-nest sites.

4.2.4 Vegetation class composition

Vegetation class composition of 4 x 4, 16 x 16 and 32 x 32 meter nest and non-nest sites is shown in Figure 4.8 and Table 4.4. Chi-square tests for independence indicate overall vegetation composition at nest sites was significantly different than in non- nest sites at the 32 x 32 (χ^2 = 298.0, P<0.001), 16 x 16 (χ^2 =279.3, P < 0.001) and 4 x 4 (χ^2 = 113.8, P < 0.001) meter scales. In general, there was proportionately less grass, and more forbs, shrubs, and trees in nest sites at all scales. These differences are most pronounced at the 4 x 4 meter scale and least pronounced at the 32 x 32 meter scale. Paired t-tests confirm that there was significantly less grass in 4 x 4 (t = -3.12, P = 0.003, 63 d.f.) 16 x 16 (t = -2.95, P = 0.004, 63 d.f) and 32 x 32 (t = -2.14, P = 0.036, 63 d.f.) meter nest sites, significantly more forb in 4 x 4 (t = 2.31, P = 0.024, 63 d.f.) 16 x 16 (t = 2.67, P = 0.010, 63 d.f) and 32 x 32 (t = 3.34, P = 0.001, 63 d.f.) meter nest sites, and significantly more shrub in 16 x 16 meter nest sites (t = 2.27, P = 0.026, 63 d.f.). Paired t-tests performed on other vegetation categories and scales were not statistically significant. Results of these tests are summarized in Table 4.4.

4.2.5 Habitat and vegetation class diversity

Shannon Weaver Diversity Indices calculated from nest and non-nest vegetation and PHJV habitat class composition data are presented in Figures 4.9 and 4.10 and Table 4.5. Vegetation class and PHJV habitat class diversity were greater at 4 x 4 meter nest sites than at non-nest sites ($t = 2.43$, $P=0.009$, 63 d.f and $t = 2.48$, $P=0.008$, 63 d.f., respectively).

A large proportion of 4 x 4 (96%), 16 x 16 (80%) and 32 x 32 (48 %) meter nest and non-nest sites in planted cover had zero PHJV habitat class diversity values, which caused the overall distribution to be strongly skewed. Transformation of the data did not serve to make the distribution more normal. Habitat class diversity was not significantly different in nest and non-nest sites in planted cover ($n = 30$) at the 4 x 4 ($t = 0.350$, $P=0.364$, 29 d.f.), 16 x 16 ($t = 1.153$, $P = 0.129$, 29 d.f.), or 32 x 32 ($t = -0.275$, $P = 0.393$, 29 d.f.) meter scales.

Paired t-test results using more normally distributed vegetation class diversity indices are virtually identical to overall habitat class diversity results. Since the vegetation class data were more descriptive of planted cover sites, and were more normally distributed, they were used for subsequent spatial analysis of nest and non-nest site vegetation.

4.2.6 Vegetation class edge scores

Vegetation class edge scores were developed to determine if the interspersion of vegetation in nest sites differed from that in non-nest sites. Mean edge score results for 4

x 4, 16 x 16 and 32 x 32 meter nest and non-nest sites are presented in Table 4.6 and

Figure 4.11. In keeping with vegetation composition and diversity results, edge scores

for 4 x 4 meter nest sites were significantly higher than in non-nest sites (t = 2.83, P =

0.003, 63 d.f.). Although earlier vegetation diversity results indicated 16 x 16 and 32 x

32 meter nest sites were not significantly different from non nest sites, mean edge scores

were significantly greater in nest sites than in non-nest sites (t = 2.18, P = 0.016, 63 d.f.

and t = 3.04, P = 0.002, 63 d.f., respectively), indicating a greater interspersion of

vegetation classes at these scales. Differences between nest and non-nest edge scores

were most pronounced at the 4 x 4 meter scale, where nest edge scores were 174% of

non-nest edge scores. Edge scores in 16 x 16 and 32 x 32 meter nest sites were

respectively 131% and 129% of corresponding non-nest edge scores.

4.2.7 Surface plots of mean VOR

Mean VORs were calculated for each sampling point across all nest and non-nest sites at

the 4 x 4, 16 x 16 and 32 x 32 meter scales. Results for 32 x 32 and 16 x16 meter data

are presented in surface plots in Figures 4.12 and 4.13, respectively. Since VORs were

collected in a 9 x 1 matrix at the 4 x 4 meter scale, these mean VORs are presented in line

plots in Figure 4.14. At all scales, mean VORs appear to be uniformly higher in nest sites

than in non-nest sites. In 32 x 32 meter nest sites, higher mean VORs are present

immediately west and south of nests, and VORs appear to increase closer to the nest.

Relatively low mean VOR values occur at the periphery of the 32 x 32 meter nest sites.

In contrast, 32 x 32 meter non-nest sites appear more uniform, although lower mean VOR

values occur in south-east and south-west portions of the site, and higher values occur

immediately north-west and south-west of non-nest grid centres. Like 32 x 32 meter nest sites, 16 x 16 meter nest sites exhibit higher relative mean VORs west of the nest, but also show irregular areas of low VOR to the south-east and north-east. The 16 x 16 meter non-nest site appears relatively more uniform than the corresponding nest site, although like the 32 x 32 meter non-nest site, clusters of higher mean VOR values occur north-west and south west of the non-nest site centre, and relatively low VOR values occur irregularly along the eastern edge of the site. At the 4 x 4 meter scale, mean VORs in non-nest sites appear to be distributed randomly in space. In comparison, mean VOR values in 4 x 4 meter nest sites increase from the south to the north, peak at the nest site, and generally decrease north of the nest site. Overall, higher mean VOR values also occur at points south of the nest location than north of the nest location in 4 x 4 meter nest sites.

4.2.8 Variation of visual obstruction with direction from the nest

Results of pairwise comparisons of VORs collected north and south of nests in 4 x 4 and 16 x 16 meter sample grids are presented in Table 4.7. An 8 x 8 meter subset of the 16 x 16 meter grid data, consisting of a 2 x 9 matrix of sample points centered on the nest, was also tested. VORs measured at the nest bowl were excluded from the analysis. Mean VOR was higher south of nests at the 4 x 4, 16 x 16 and 8 x 8 meter scale, but these differences were not statistically significant ($t = -1.01$, $P = 0.158$, 63 d.f.; $t = -0.402$, $P=0.344$, 63 d.f., and $t = -0.409$, $P = 0.342$, 63 d.f., respectively).

Results of pairwise comparisons of VORs collected east and west of nests within 16 x 16 meter sample grids are presented in Table 4.8. Mean VOR was greater west of nests within 16 x 16 (t = 1.16, P=0.125, 63 d.f.) and 8 x 8 (t = 1.82, P=0.037, 63 d.f.) meter subsets of the 16 x 16 meter data, but this difference was statistically significant only at the 8 x 8 meter scale. To verify that this pattern was related to nest site selection behavior, a pair-wise comparison was conducted for a similar 8 x 8 meter subset of the 16 x 16 meter non-nest data (Table 4.9); although mean VOR was higher for points west of non-nest grid centres, this difference was not statistically significant (t = 1.38, P=0.086, 63 d.f.).

4.2.9 Spatial autocorrelation

Results of paired t-tests of Moran's I z-statistics are presented in Table 4.10 for 16 x 16 and 32 x 32 meter nest and non-nest sites. In general, z-statistics greater than zero correspond to positively autocorrelated surfaces, negative z-values correspond to negatively autocorrelated surfaces, and "neutral" or near-zero values correspond to surfaces that vary randomly in space (Figure 4.15). Overall, 16 x 16 and 32 x 32 meter VOR surfaces at nest sites appears to be more random, or variable, than more positively autocorrelated non-nest sites, but results varied considerably between nest and non-nest sites (Figure 4.16). Overall results were similar using both distance metrics, although z-statistics were higher for both nest and non-nest sites when the 1/ED metric was used and distant values had greater influence on the calculation of the z-statistic.

4.3 Changes in vegetation characteristics over time: permanent transect results

4.3.1 Mean visual obstruction and vegetation height

During the period when nest and non-nest data were collected, mean vegetation height and VOR in permanent transects increased in a continuous, roughly linear fashion (Figure 4.17). This pattern was consistent for transects in grass-shrub and planted cover. Mean vegetation height increased from 50.1 cm to 89.3 cm, and mean VOR increased from 1.48 to 4.89 over the seven weeks that permanent transect data were collected. Mean VOR and vegetation height was consistently lower in grass-shrub transects and consistently higher in planted cover transects for the duration of study. During a typical 14 day interval between nest site selection and measurement of vegetation at nest sites, simple linear regression models fit to the data predict mean vegetation height and VOR would have increased 27% ($r^2 = 0.906$) and 142% ($r^2 = 0.9412$), respectively.

4.3.2 Coefficient of variation of visual obstruction and vegetation height

Coefficient of variation of VOR declined in permanent transects in a roughly linear fashion over the duration of study (Figure 4.18). This was consistent with casual observations of nesting cover in the study area: a heterogeneous pattern of dead residual vegetation created by variable, patchy snow pack, herbivory and other influences gradually gave way to taller, more homogenous stands of grasses and forbs. Individual plant species (e.g. alfalfa and other forbs) showed periods of rapid growth, accompanied by patchy increases in vegetation volume in mid-spring. This may have caused the observed increase in CV of VOR between May 28 and June 4. After this date, vegetation volume along transects appeared more uniform, explaining the decrease in variability.

Grass shrub transects were more variable after May 28 than planted cover transects, perhaps because of differences in plant species composition and management regime.

CV of vegetation height also declined in a roughly linear fashion over the duration of study, but more slowly than CV of VOR. Variability in vegetation height differed early but converged late in the nesting season in grass-shrub and planted cover sites.

During a typical 14 day interval between nest site selection and measurement of vegetation at experimental sites, simple linear regression models predict average CV of VOR and CV of vegetation height declined 12.9% ($r^2 = 0.904$) and 9.0% ($r^2 = 0.921$), respectively.

4.3.3 Vegetation class diversity

Overall, vegetation class diversity gradually increased in a linear fashion over the duration of study (Figure 4.19). Diversity of planted cover transects remained relatively constant and diversity of grass-shrub transects increased over this period. Diversity was initially lowest, but was highest by the end of study, in grass shrub transects. During a typical 14 day interval between nest site selection and measurement of vegetation at nest sites, a simple linear regression model fit to the data predicts average vegetation diversity increased approximately 16% ($r^2 = 0.8311$). Variability in the temporal effect on vegetation diversity at nest sites was affected by the cover type, date of nest initiation, and time interval between nest initiation and vegetation measurement.

Table 4.1: Mean VOR and mean vegetation height for 4 x 4, 16 x 16 and 32 x 32 meter nest and non-nest sites.

Sampling scale	Type	df	Mean VOR	SD	t-statistic	P-value	Mean Vegetation height	SD	t-statistic	P-value
4 x 4 meter	Nest	63	3.05	1.44	2.55	0.007	62.89	19.63	1.67	0.050
	Non-nest	63	2.51	1.57			59.31	22.06		
16 x 16 meter	Nest	63	2.73	1.35	3.60	<0.001	60.28	21.19	2.32	0.012
	Non-nest	63	2.28	1.33			56.37	21.59		
32 x 32 meter	Nest	63	2.53	1.36	3.34	0.001	56.55	21.58	1.63	0.054
	Non-nest	63	2.17	1.28			53.91	21.80		

Table 4.2: Coefficient of Variation (CV) of VOR and vegetation height for 4 x 4, 16 x 16 and 32 x 32 meter nest and non-nest sites.

Sampling scale	Type	df	Mean CV of VOR	SD	t-statistic	P-value	Mean CV of Vegetation height	SD	t-statistic	P-value
4 x 4 meter	Nest	63	33.17	14.98	-0.982	0.165	28.57	30.08	1.793	0.039
	Non-nest	63	35.70	17.72			21.78	9.54		
16 x 16 meter	Nest	63	59.23	43.38	0.677	0.250	36.66	24.80	-0.250	0.401
	Non-nest	63	56.12	30.55			37.42	21.97		
32 x 32 meter	Nest	63	67.45	45.51	-0.502	0.309	43.94	27.74	-0.410	0.341
	Non-nest	63	70.11	40.71			45.28	28.61		

Table 4.3: PHJV Habitat Cover Composition of 4 x 4, 16 x 16 and 32 x 32 meter nest and non-nest sites.

Sampling scale	Type	p(Grassland)	p(Shrubland)	p(Planted)	p(Wetland)	p(Cropland)	p(Woodland)	p(Other)	χ^2 Test for Independence
4 x 4 meter	Nest	0.345	0.124	0.453	0.0357	0.029	0.010	0.002	χ^2= 69.55 P<0.001 4 d.f.
	Non-nest	0.468	0.040	0.459	0.0123	0.014	0	0	
P-value (t-statistic, d.f.)		**0.003** (-2.81, 63)	**0.012** (2.30, 63)	0.383 (-0.298, 63)	0.147 (1.06, 63)	0.181 (0.916, 63)	0.065 (1.67, 63)	0.161 (1.0, 63)	
16 x 16 meter	Nest	0.319	0.083	0.461	0.0522	0.049	0.009	0.025	χ^2= 276.6 P<0.001 6 d.f.
	Non-nest	0.347	0.033	0.478	0.0591	0.082	0	0.002	
P-value (t-statistic, d.f.)		0.165 (-0.981, 63)	**0.011** (2.340, 63)	0.191 (-0.881, 63)	0.355 (-0.374, 63)	**0.046** (-1.71, 63)	**0.038** (1.79, 63)	**0.020** (2.09, 63)	
32 x 32 meter	Nest	0.269	0.051	0.448	0.0897	0.085	0.017	0.037	χ^2= 203.5 P<0.001 6 d.f.
	Non-nest	0.256	0.031	0.459	0.111	0.126	0.004	0.010	
P-value (t-statistic, d.f.)		0.312 (0.492, 63)	0.079 (1.42, 63)	0.258 (-0.652, 63)	0.147 (-1.059, 63)	**0.028** (-1.94, 63)	0.053 (1.64, 63)	**<0.001** (3.25, 63)	

Table 4.4: Vegetation Class Composition of 4 x 4, 16 x 16 and 32 x 32 meter nest and non-nest sites.

Sampling scale	Type	p(Grass)	p(Forb)	p(Shrub)	p(Trees)	p(Hydrophytes)	p(Annual)	p(Flooded)	p(Bare)	χ^2 Test for Independence
4 x 4 meter	Nest	0.665	0.173	0.098	0.006	0.038	0.008	0.003	0.010	χ^2= 113.8 P<0.001 5 d.f.
	Non-nest	0.829	0.091	0.047	0.000	0.016	0.009	0.000	0.008	
P-value (t-statistic, d.f.)		**0.003** (-3.12, 63)	**0.024** (2.31, 63)	0.107 (1.63, 63)	0.083 (1.76, 63)	0.349 (0.944, 63)	0.761 (-0.306, 63)	0.321 (1.00, 63)	0.768 (0.296, 63)	
16 x 16 meter	Nest	0.605	0.174	0.084	0.010	0.028	0.017	0.027	0.055	χ^2= 279.3 P<0.001 7 d.f.
	Non-nest	0.722	0.098	0.034	0.000	0.030	0.027	0.024	0.065	
P-value (t-statistic, d.f.)		**0.004** (-2.95, 63)	**0.010** (2.67, 63)	**0.026** (2.27, 63)	0.075 (1.81, 63)	0.905 (-0.120, 63)	0.438 (-0.781, 63)	0.798 (0.258, 63)	0.603 (-0.523, 63)	
32 x 32 meter	Nest	0.547	0.188	0.052	0.017	0.034	0.028	0.056	0.079	χ^2= 298.0 P<0.001 7 d.f.
	Non-nest	0.622	0.104	0.032	0.004	0.040	0.042	0.069	0.087	
P-value (t-statistic, d.f.)		**0.036** (-2.14, 63)	**0.001** (3.34, 63)	0.173 (1.38, 63)	0.093 (1.71, 63)	0.501 (-0.677, 63)	0.256 (-1.15, 63)	0.437 (-0.783, 63)	0.602 (-0.524, 63)	

Table 4.5: Shannon-Weaver Diversity Index for PHJV Habitat Cover (CL-DIV) and Vegetation Class (VEG-DIV) in 4 x 4, 16 x 16 and 32 x 32 meter nest and non-nest sites.

Sampling scale	Type	d.f.	Mean CL-DIV	SD	t-statistic	P-value	Mean VEG-DIV	SD	t-statistic	P-value
4 x 4 meter	Nest	63	0.186	0.306	2.43	0.009	0.299	0.346	2.48	0.008
	Non-nest	63	0.102	0.220			0.181	0.266		
16 x 16 meter	Nest	63	0.411	0.453	-0.508	0.307	0.543	0.422	0.253	0.401
	Non-nest	63	0.435	0.422			0.530	0.488		
32 x 32 meter	Nest	63	0.637	0.484	0.349	0.364	0.786	0.501	0.977	0.166
	Non-nest	63	0.619	0.475			0.737	0.518		

Table 4.6: Edge analysis scores for vegetation in 4 x 4, 16 x 16 and 32 x 32 meter nest and non-nest sites.

Sampling scale	Type	d.f.	mean edge score	SD	t-statistic	P-value
4 x 4 meter	Nest	63	5.77	23.58	2.83	0.003
	Non-nest	63	3.31	27.17		
16 x 16 meter	Nest	63	16.94	14.76	2.18	0.016
	Non-nest	63	12.88	13.63		
32 x 32 meter	Nest	63	35.48	7.06	3.04	0.002
	Non-nest	63	27.45	26.73		

Table 4.7: Comparison of mean VOR for sampling points north and south of nest sites (4x4 and 16x16 meter site data).

Site data used	Mean VOR north of nest	Mean VOR south of nest	d.f.	SD	t-statistic	P-value
4x4	3.00	3.14	63	1.55	-1.01	0.158
16x16	2.77	2.74	63	1.44	-0.402	0.344
16x16 (8x8 subset)	2.81	2.86	63	1.55	-0.409	0.342

Table 4.8: Comparison of mean VOR for sampling points east and west of nest sites (16x16 meter site data).

Site data used	Mean VOR east of nest	Mean VOR west of nest	d.f.	SD	t-statistic	P-value
16x16	2.65	2.81	63	1.38	1.16	0.125
16x16 (8x8 subset)	3.07	2.73	63	1.46	1.82	0.037

Table 4.9: Comparison of mean VOR for sampling points east and west of non-nest site centres (8x8 meter subset of 16x16 meter site data).

Site data used	Mean VOR east of nest	Mean VOR west of nest	d.f.	SD	t-statistic	P-value
16x16 (8x8 subset)	2.33	2.50	63	1.45	1.38	0.086

Table 4.10: Moran's I z-statistics for VORs collected across 16 x 16 and 32 x 32 meter nest and non-nest sites.

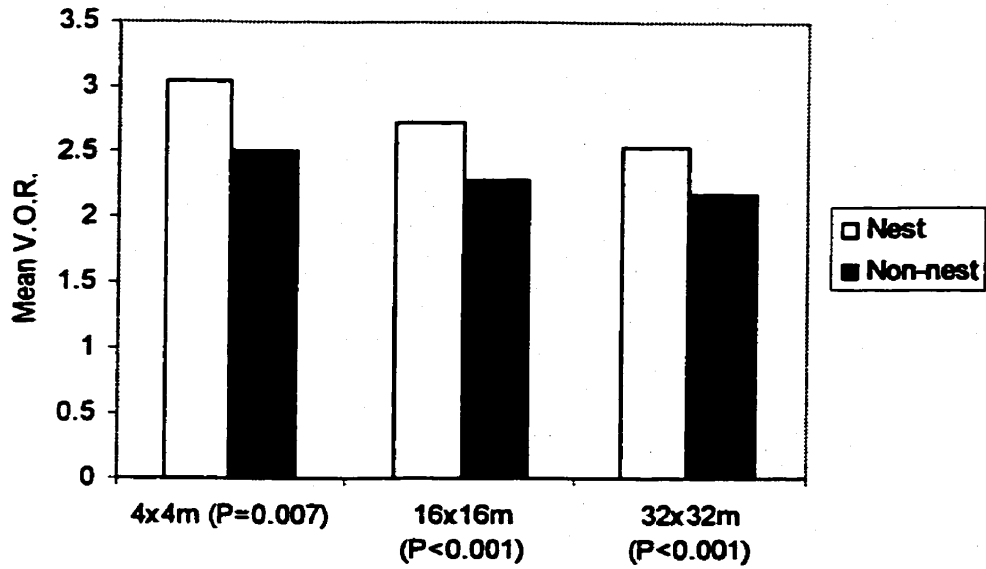| Sampling scale	Type	z-statistic ($1/ED^2$)	SD	t-statistic	P-value	d.f.	z-statistic ($1/ED$)	SD	t-statistic	P-value	d.f.
16 x 16 meter	Nest	2.15	1.32	-1.03	0.304	63	2.75	1.68	-1.06	0.292	63
	Non-nest	2.33	1.39			63	3.00	1.80			63
32 x 32 meter	Nest	2.25	1.48	-1.45	0.153	63	2.73	1.75	-1.51	0.135	63
	Non-nest	2.54	1.54			63	3.11	1.88			63

Figure 4.1: Mean VOR in 4x4, 16x16 and 32x32 meter nest and non-nest sites (n=64)
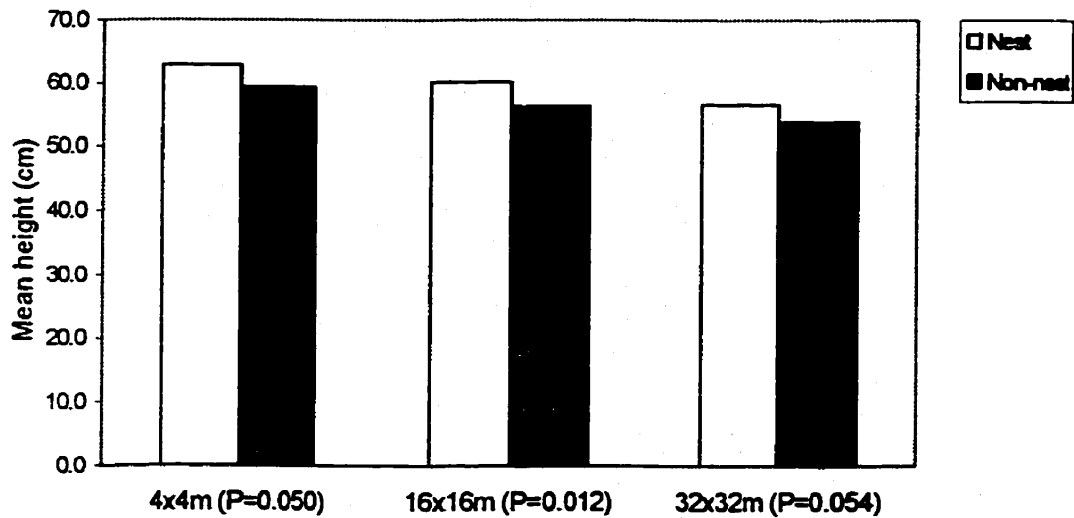

Figure 4.2: Mean vegetation height in 4x4, 16x16 and 32x32 meter nest and non-nest sites (n=64)
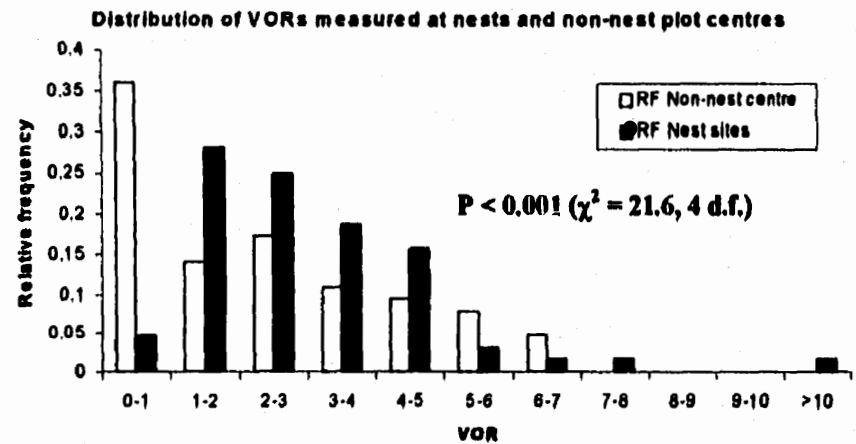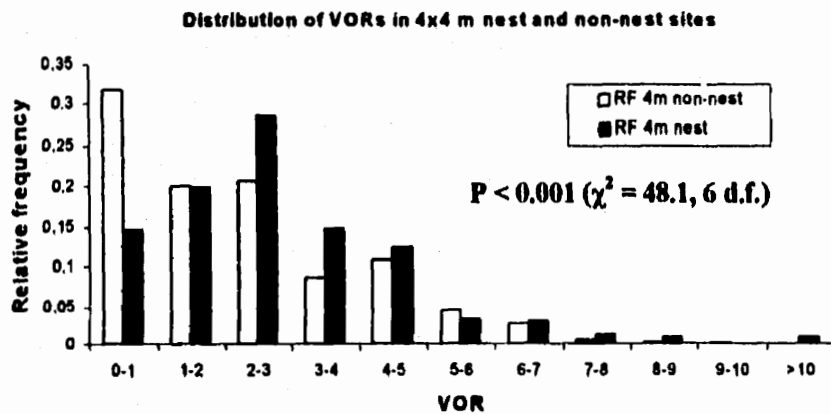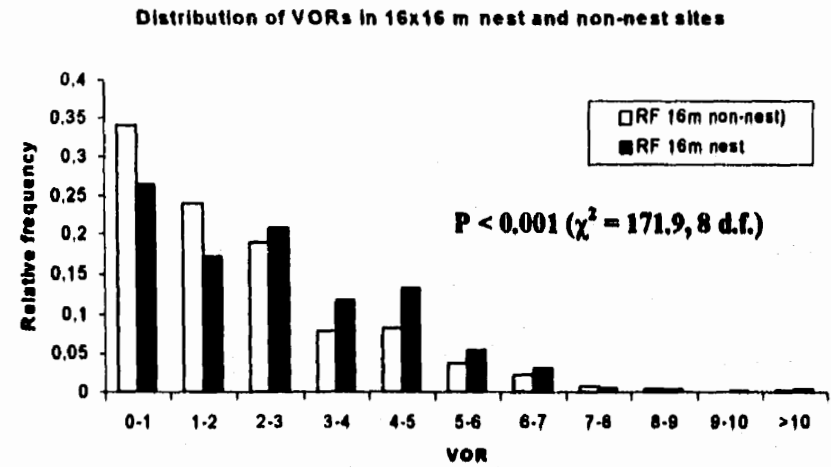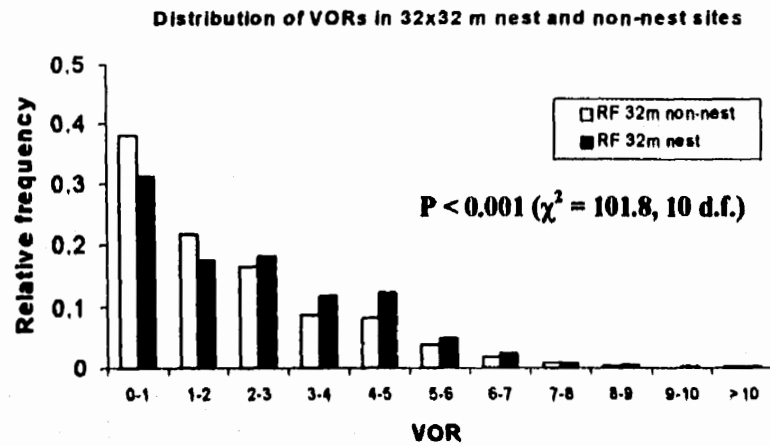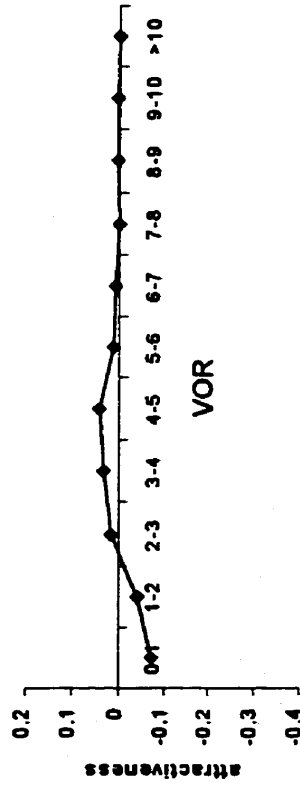
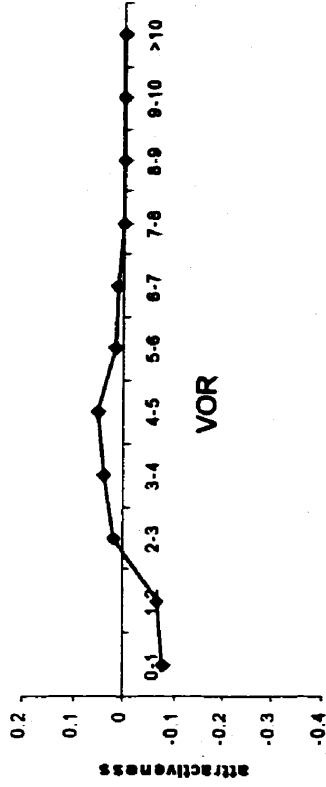**Figure 4.3**: Distribution of VORs measured at nest and non nest site centres and in 32x32, 16x16, 4x4 meter nest and non nest sites.
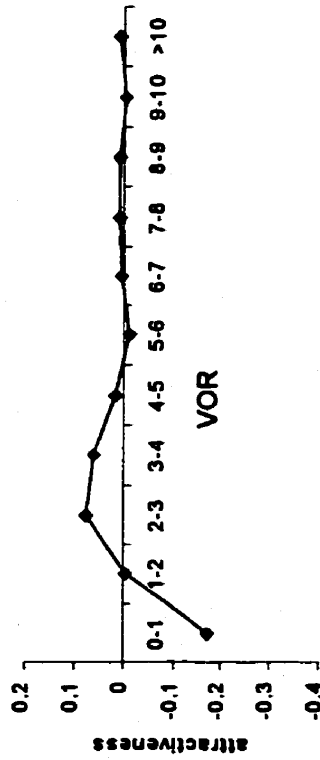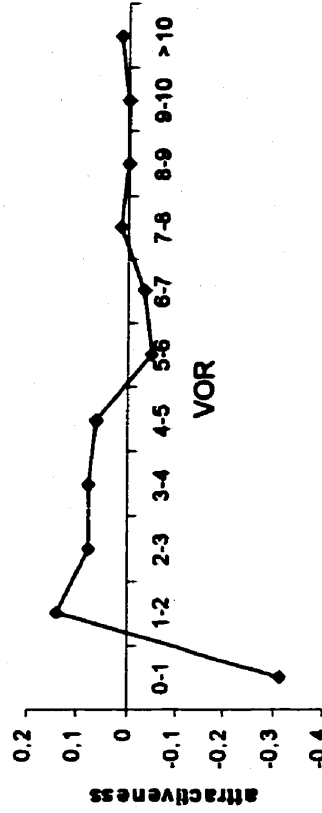
Figure 4.4: Difference between use and availability of VORs in 32x32, 16x16 and 4x4 meter sites and at nest sites non-nest site centres

Figure 4.5: Mean Coefficient of Variation of VOR in 4x4, 16x16 and 32x32 meter nest and non-nest sites (n=64)
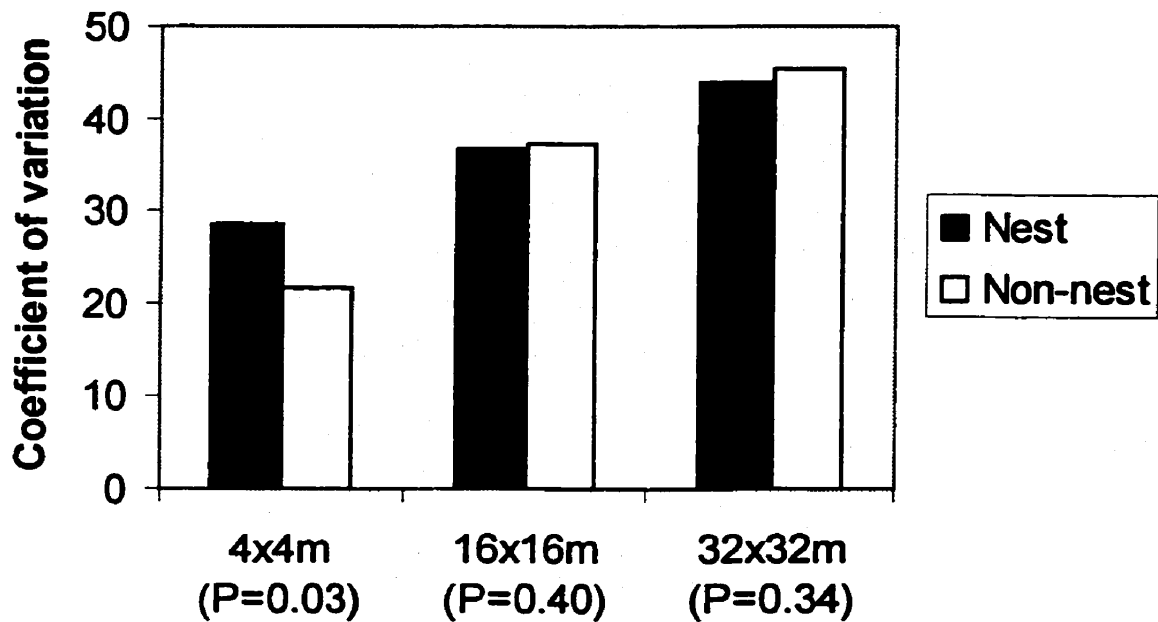
Figure 4.6: Mean coefficient of variation of vegetation height in 4x4, 16x16 and 32x32 meter nest and non-nest sites.

PHJV Habitat Cover Composition in 32x32 meter nest and non-nest plots

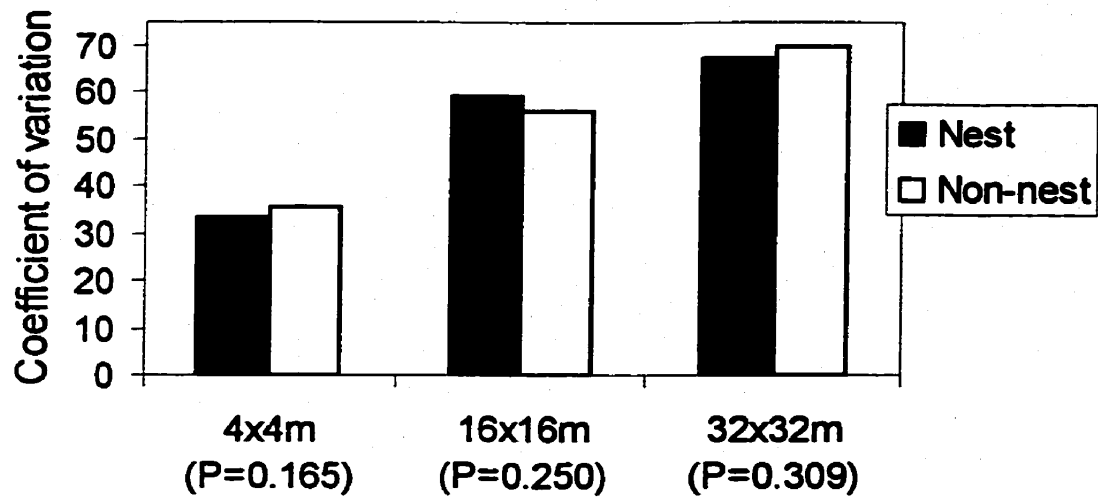P < 0.001 (χ^2 = 203.5, 6 d.f.)

Proportion (y-axis: 0 to 0.5)

Categories: Grass, Shrub, Planted cover, Wetland, Cropland, Woodland, Other

Legend: ■ Nest □ Non-nest
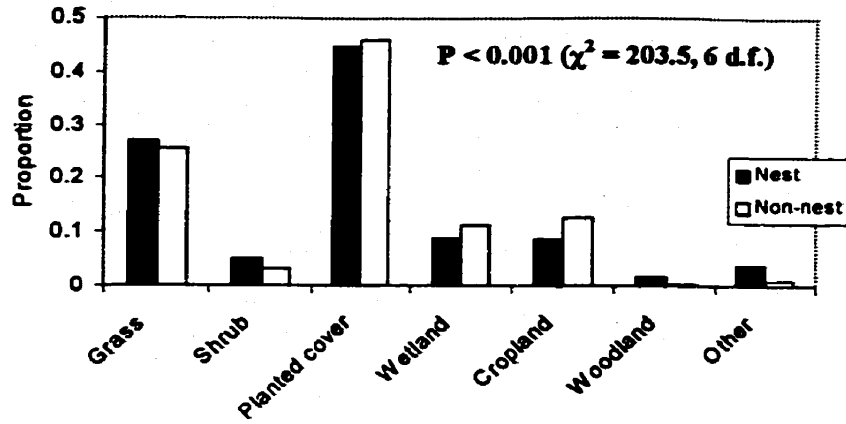
PHJV Habitat Cover Composition in 16x16 meter nest and non-nest plots

P < 0.001 (χ^2 = 276.6, 6 d.f.)

Proportion (y-axis: 0 to 0.5)

Categories: Grass, Shrub, Planted cover, Wetland, Cropland, Woodland, Other

Legend: ■ Nest □ Non-nest
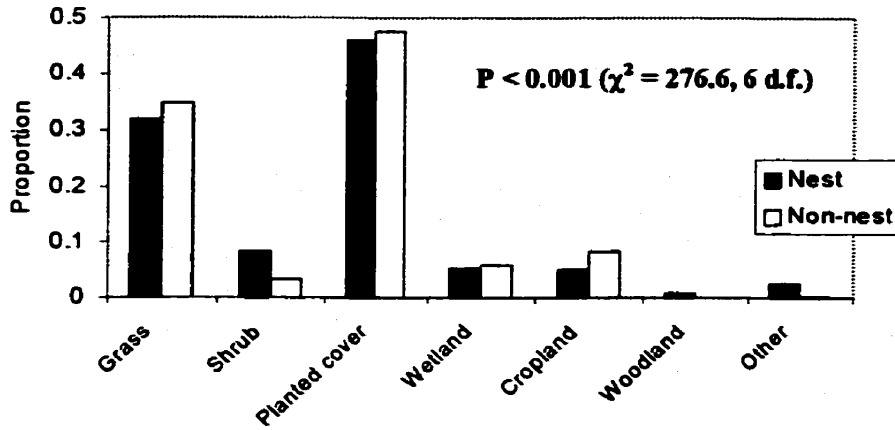
PHJV Habitat Cover Composition in 4x4 meter nest and non-nest plots

P < 0.001 (χ^2 = 69.5, 4 d.f.)

Proportion (y-axis: 0 to 0.5)

Categories: Grass, Shrub, Planted cover, Wetland, Cropland, Woodland, Other

Legend: ■ Nest □ Non-nest
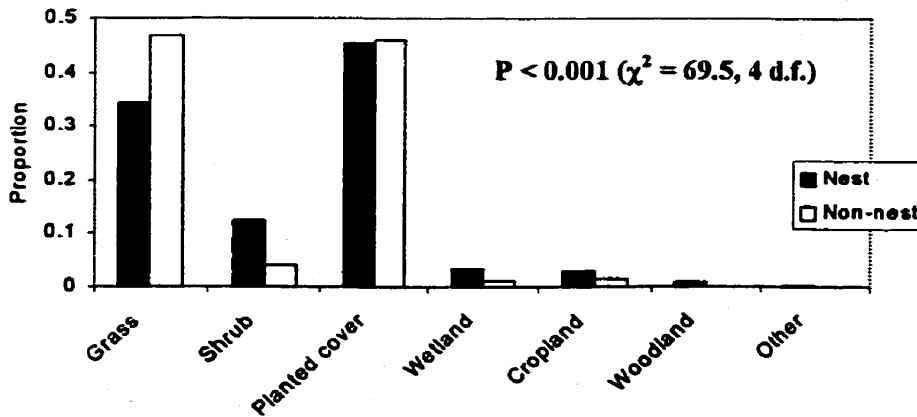
Figure 4.7: PHJV habitat cover class composition of 4x4, 16x16 and 32x32 meter nest and non-nest sites.
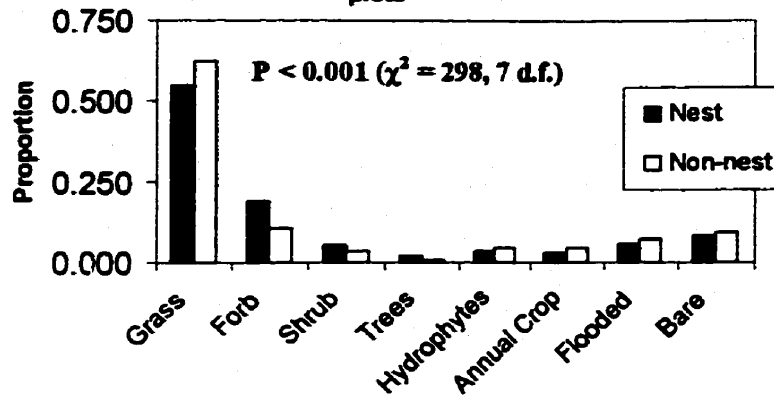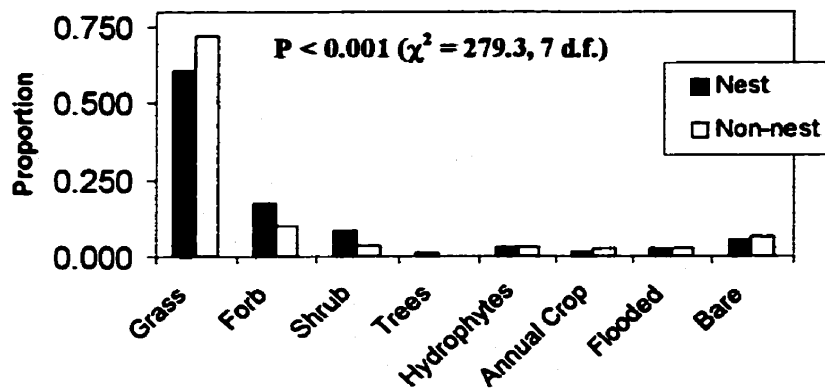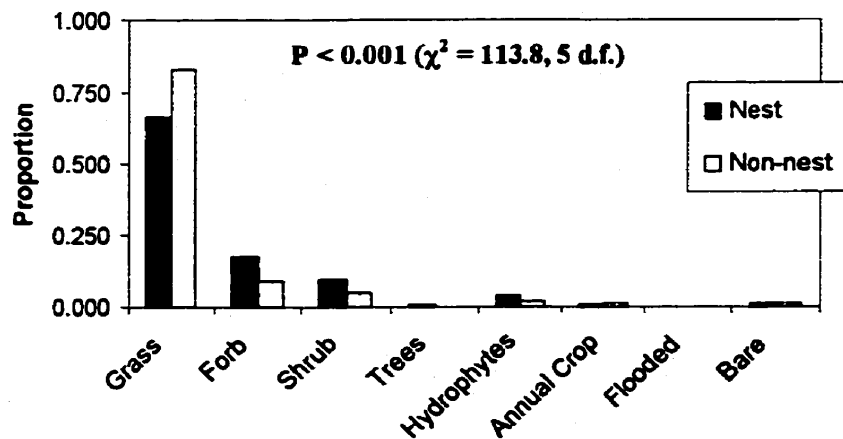
Figure 4.8: Vegetation cover class composition of 4x4, 16x16 and 32x32 meter nest and non-nest sites.
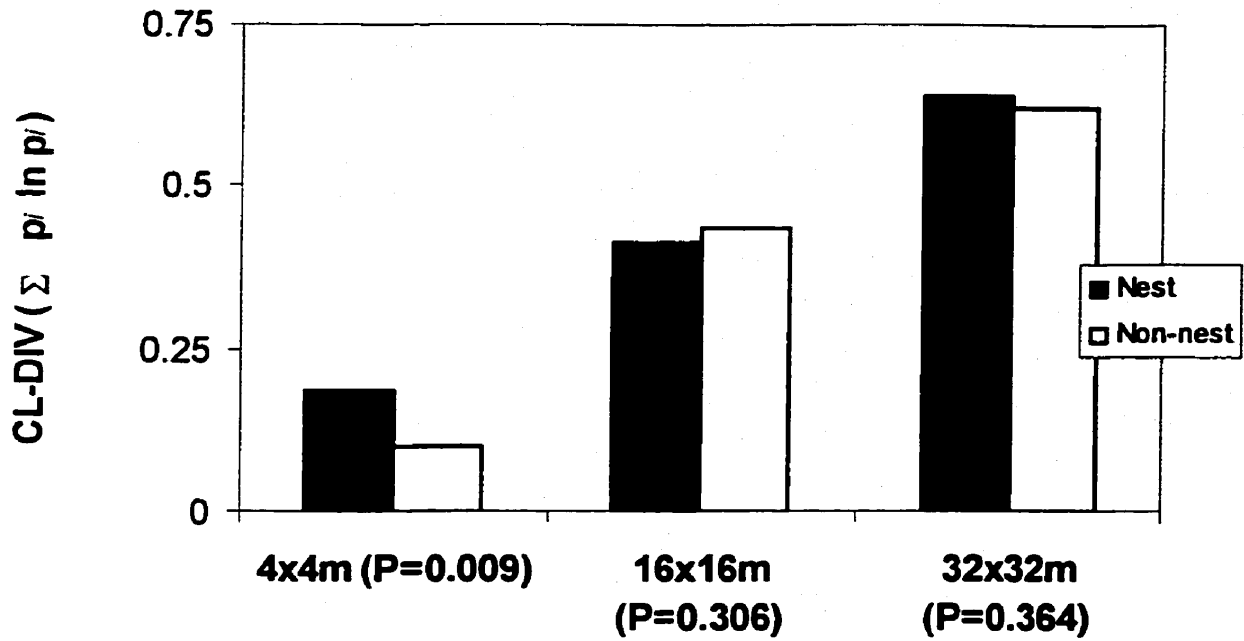
Figure 4.9: Mean Shannon Weaver Diversity Indices for PHJV habitat class (CL-DIV) in 4x4, 16x16 and 32x32 meter nest and non-nest sites.
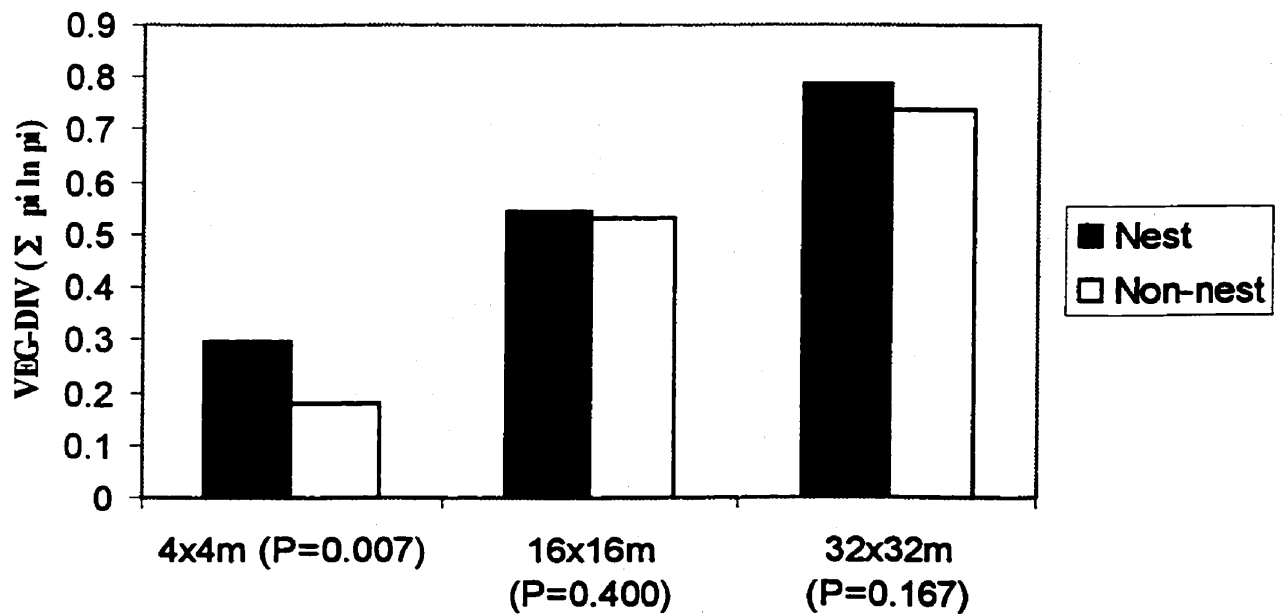
Figure 4.10: Mean Shannon Weaver Diversity Indices for vegetation class (VEG-DIV) in 4x4, 16x16 and 32x32 meter nest and non-nest sites.
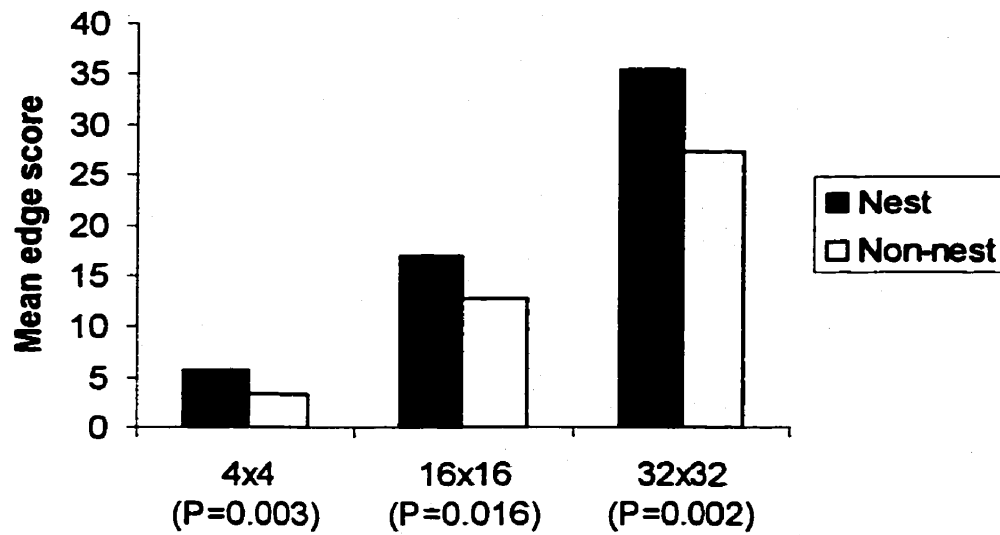
Figure 4.11: Mean edge scores in nest and non-nest sites

Mean VOR across 32x32 meter nest plots
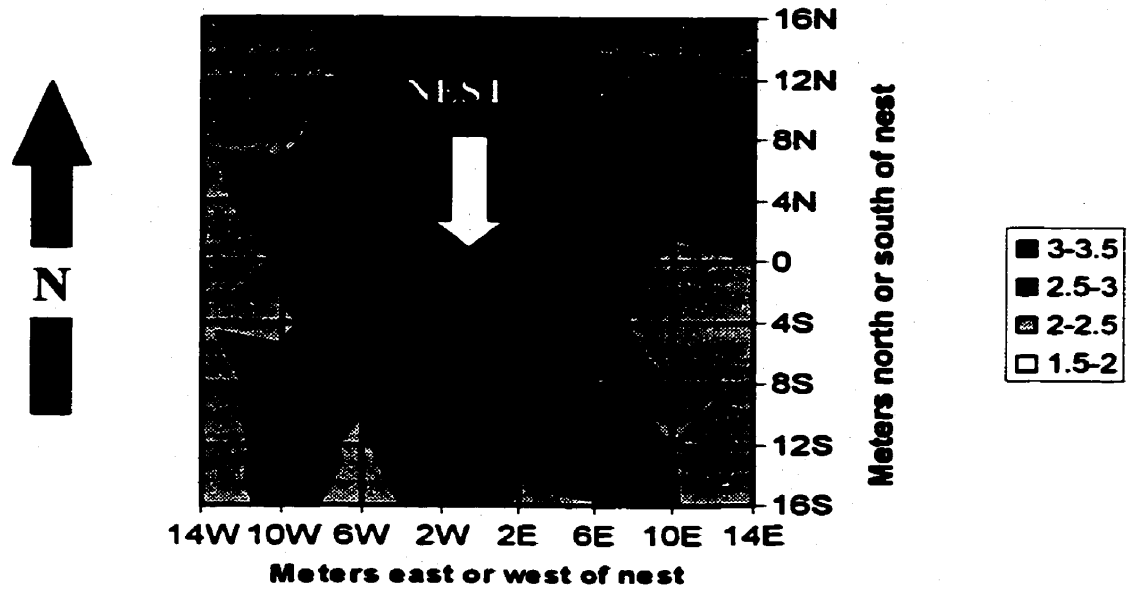
Mean VOR across 32x32 meter non-nest sites
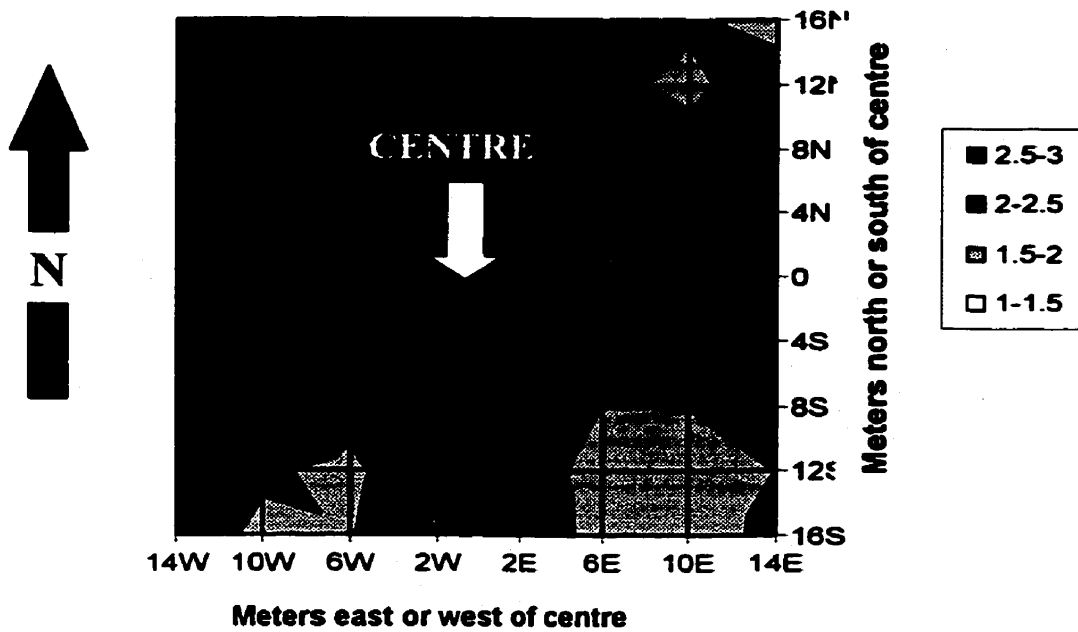
Figure 4.12: Mean VOR across 32x32 meter nest and non-nest sites

Figure 4.13: Mean VOR across 16x16 meter nest and non-nest sites.
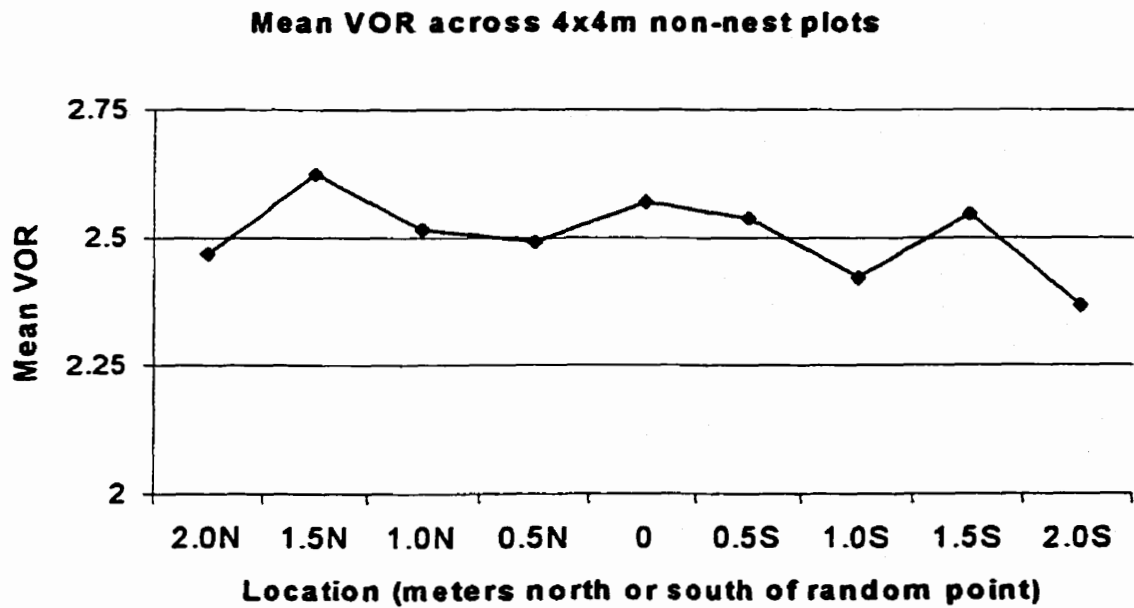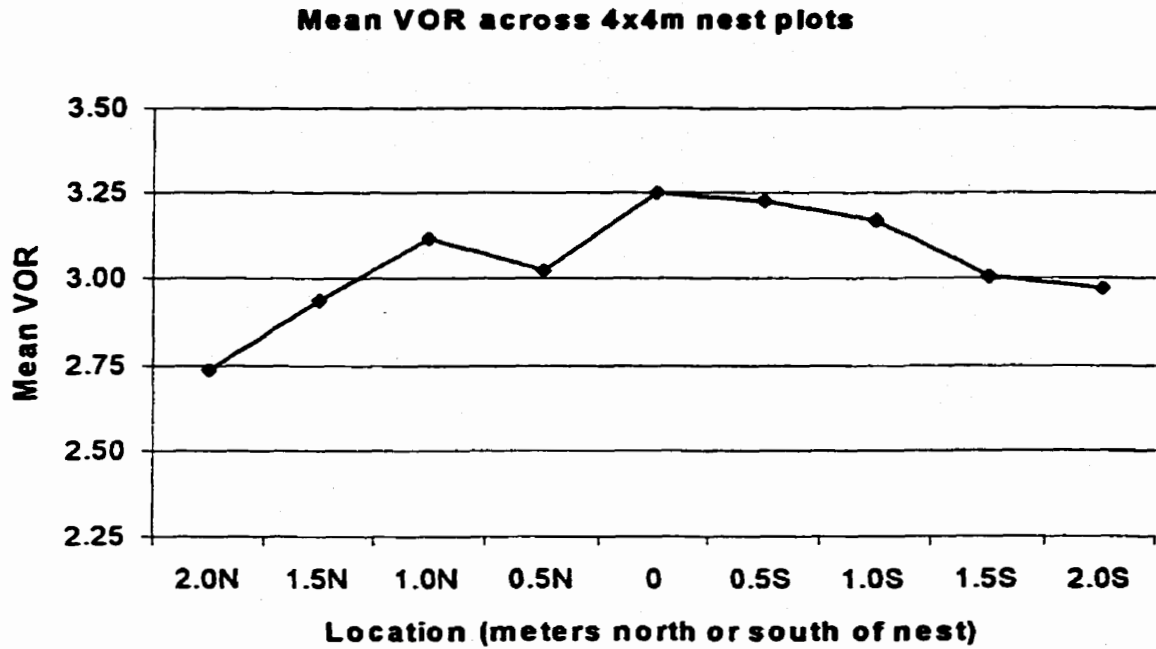
Figure 4.14: Mean VOR across 4x4 meter nest and non-nest sites.

test slope

z-statistic (1/ED) = 11.4
z-statistic (1/ED^2) = 8.85

test mound

z-statistic (1/ED) = 5.73
z-statistic (1/ED^2) = 5.81

test multi-hump

z-statistic (1/ED) = -0.825
z-statistic (1/ED^2) = -1.71

test random

z-statistic (1/ED) = 1.11
z-statistic (1/ED^2) = 1.03
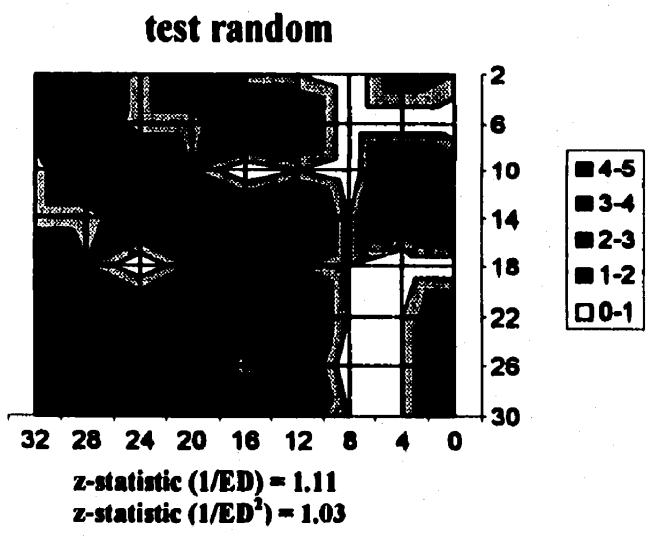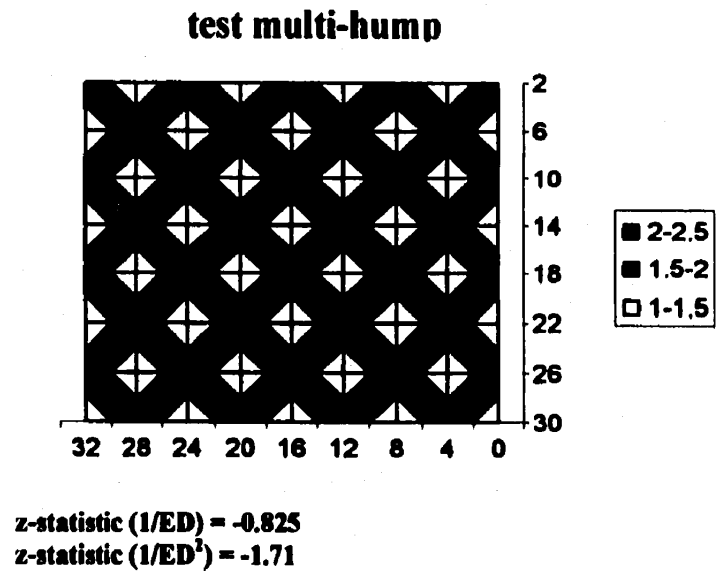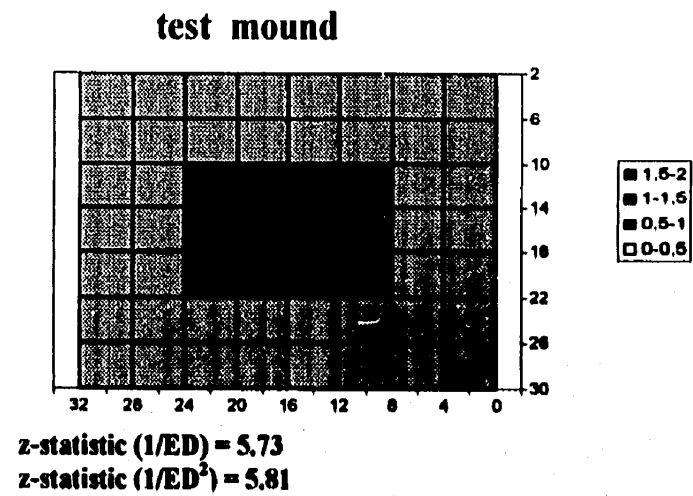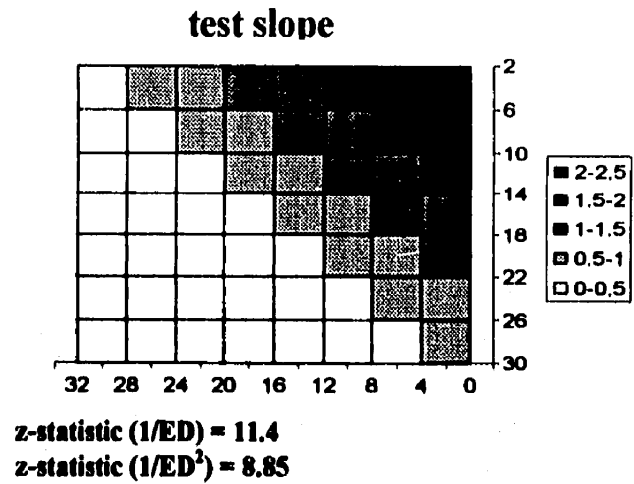
Figure 4.15: Moran's I z-statistics for slope, hump, random and multi-hump test surfaces

VOR surface plot of nest site #0465 (32 x 32 m.)

VOR surface plot of nest site #0357 (32 x 32 m.)

VOR surface plot of non-nest site #0465 (32 x 32 m.)

VOR surface plot of non-nest site #0357 (32 x 32 m.)
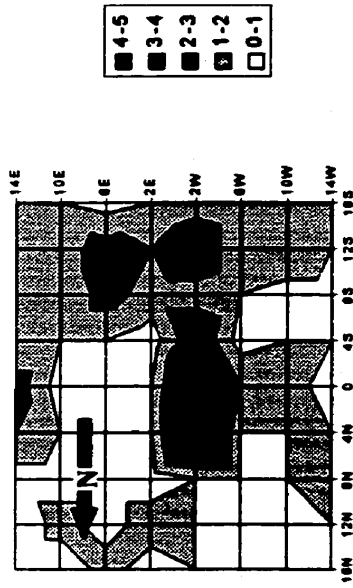
Z-statistic (1/ED) = 2.31
z-statistic (1/ED^2) = 2.09
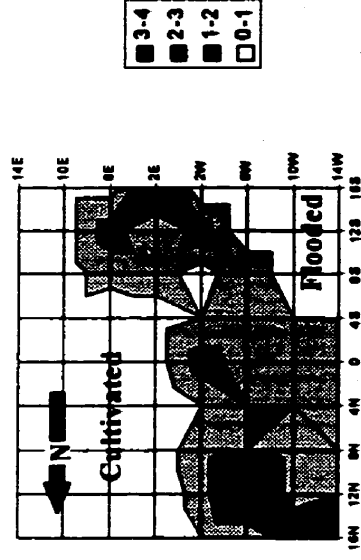
Z-statistic (1/ED) = 5.18
z-statistic (1/ED^2) = 4.12
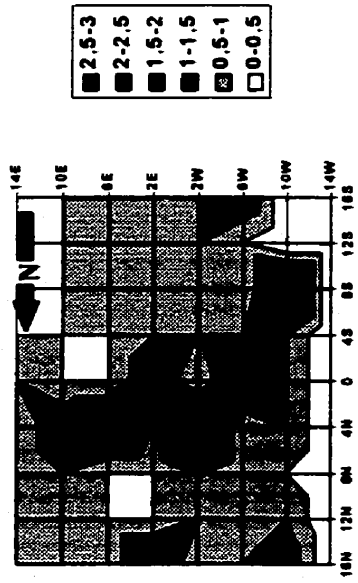
Z-statistic (1/ED) = 0.446
z-statistic (1/ED^2) = 0.036
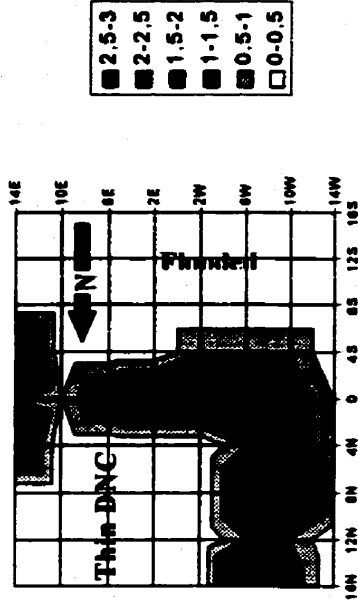
Z-statistic (1/ED) = 2.61
z-statistic (1/ED^2) = 2.14

Figure 4.16: VOR surface sites and Moran's I z-statistics for sample 32x32 meter nest and non-nest data

The Roles of Heterogeneity and Scale in Mallard Nest Site Selection
Chapter 4: Results
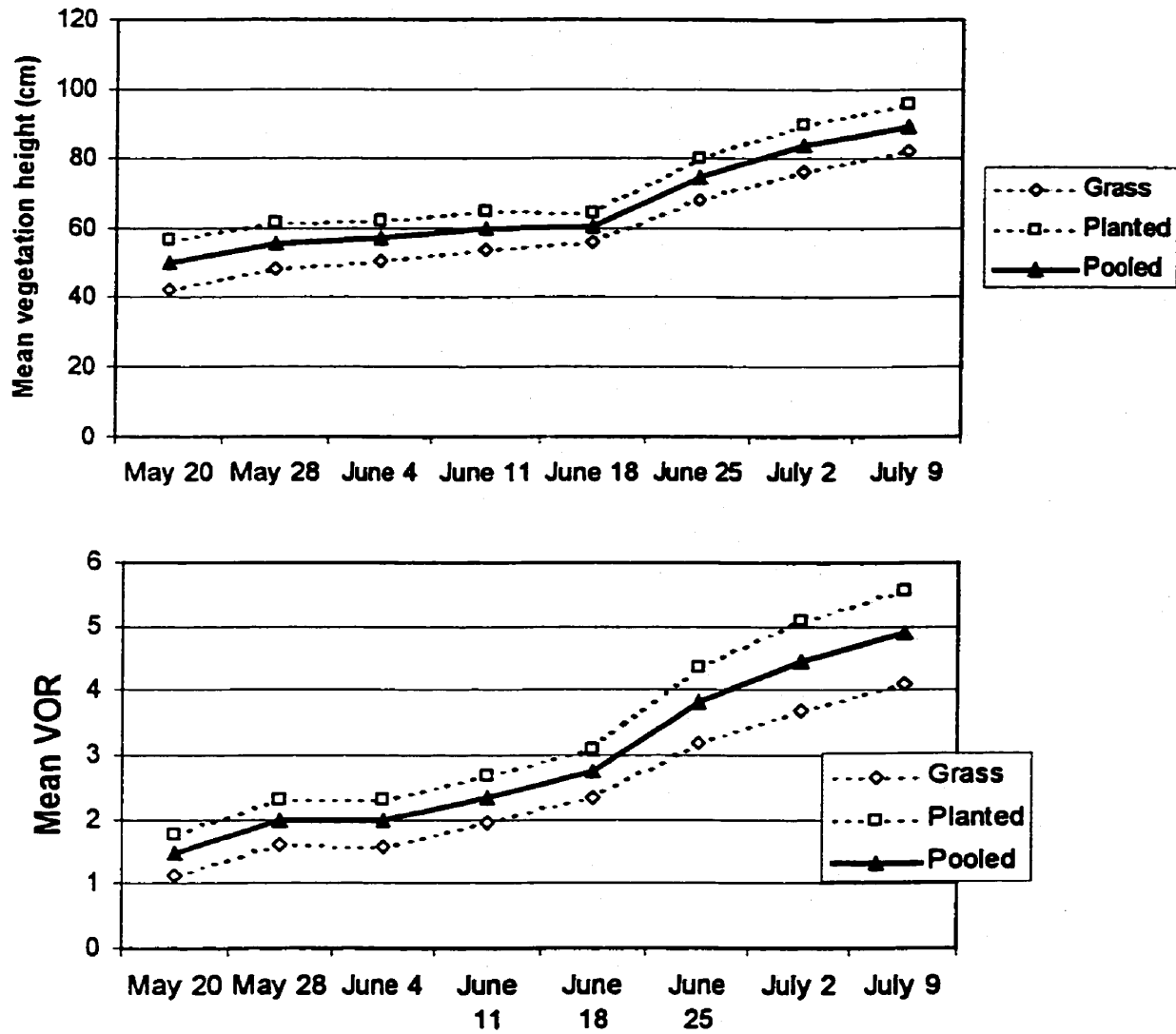
Figure 4.17: Mean vegetation height and mean VOR in permanent line transects measured weekly from May 20 – July 9, 1998.
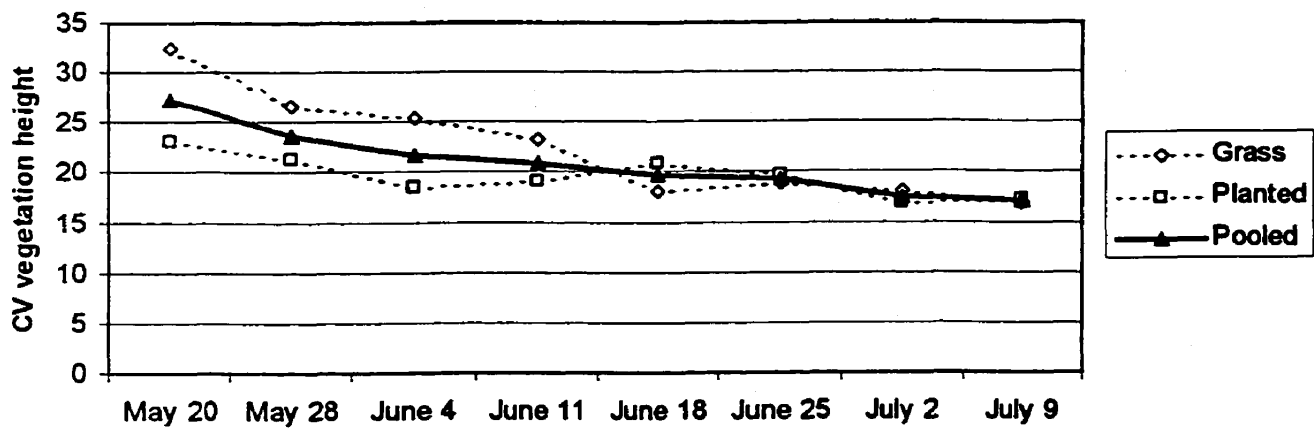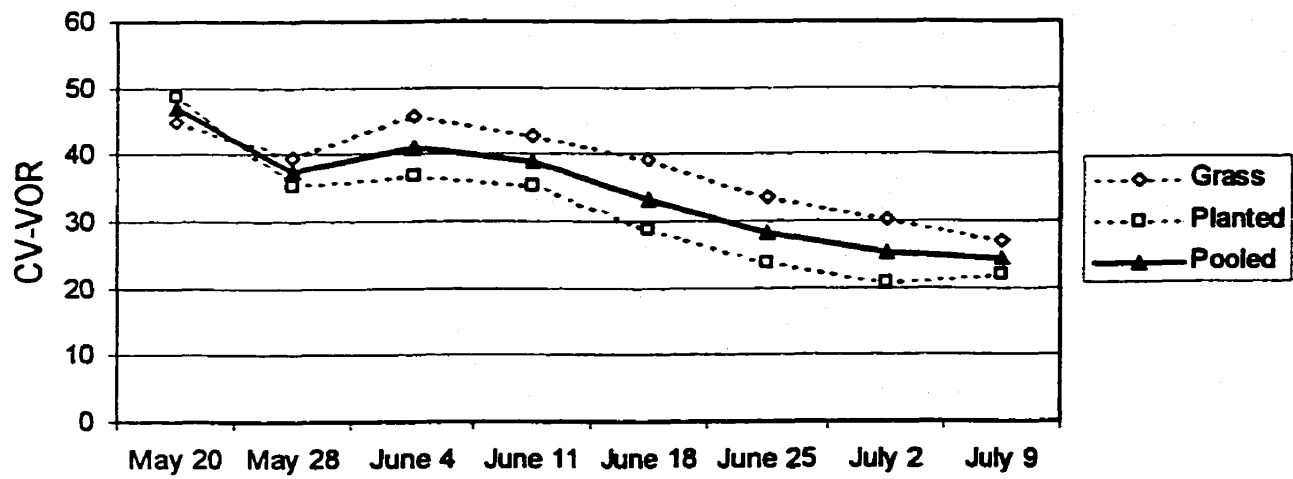
Figure 4.18: Coefficient of Variation of VOR and vegetation height in permanent line transects measured weekly May 20 – July 9, 1998.
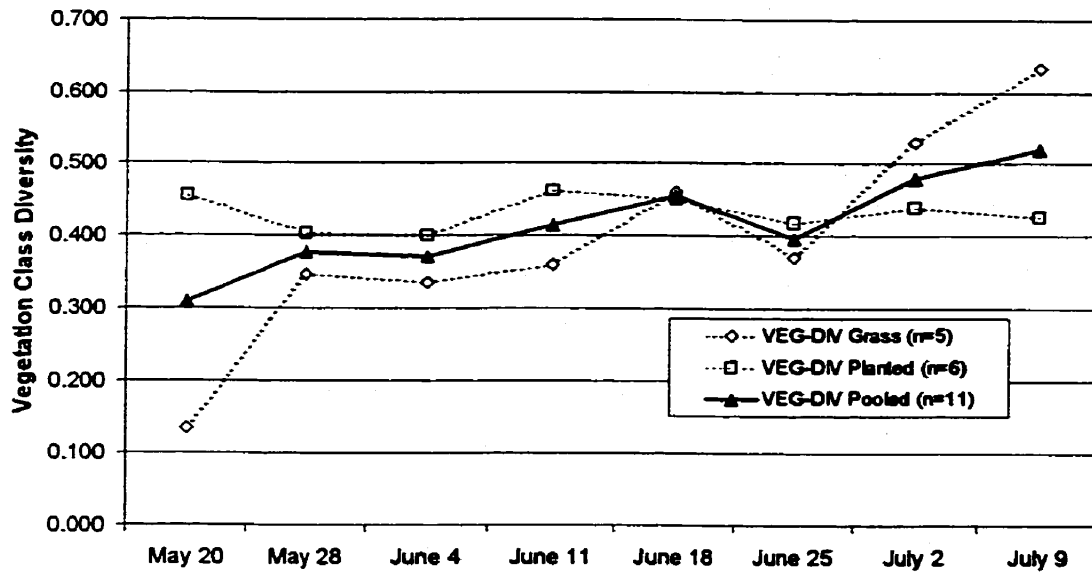
Figure 4.19: Shannon Weaver Diversity Indices for vegetation class in permanent line transects measured weekly from May 20 – July 9, 1998.

5.0 DISCUSSION

5.1 Making inferences about nest site selection by mallards

Habitat selection has been inferred when habitats were used disproportionately to their estimated availabilities (Johnson 1980) or when utilized habitats and sites differed statistically from unused or randomly selected areas (Kaminski and Weller 1992). The terms *selection* and *preference* are used interchangeably in this discussion, although preference is properly determined independent of availability (Litvaitis *et al.* 1996).

It was assumed inter- and intra-specific competition did not exclude individual mallard females from potential nesting habitats, and that all vegetation types were available to all individuals. As Anderson and Titman (1992) describe, breeding mallards use large (16 – 111 Ha), frequently overlapping territories for mating, and forage extensively (though not exclusively) there. Females usually nest within or nearby their breeding territories, although they have been known to nest as far as 5.5 km away, sometimes in very close proximity to conspecifics at highly attractive sites, such as islands. Inter-specific territoriality has not been demonstrated between mallards and other upland nesting waterfowl (Dubowy 1988). It is assumed other extrinsic influences on selection behavior (e.g. predation, population density) affected all individuals and potential habitats equally, and did not bias study results. Vegetation characteristics at nest sites are therefore assumed to reflect habitat preferences within the available habitat.

5.2 Effects of temporal change in vegetation on study results

In general, changes in vegetation height, density, variability and diversity were roughly linear over time and affected early- and late-measured nests approximately equally. Since paired nest and non-nest sites were measured at approximately the same time, relative comparisons of vegetation characteristics are assumed to be valid. It appears temporal changes between nest site selection and measurement of vegetation consistently biased study results: it is estimated that measured variability of vegetation height and density was consistently lower, measured mean height and density was consistently higher, and measured vegetation diversity was consistently higher than when nest sites were selected by females. Average estimates of vegetation characteristics should be interpreted and used accordingly.

5.3 Visual obstruction of vegetation at mallard nest sites

Most studies indicate that mallard and other dabbler nest densities increase with the height and density of available nesting cover (Duebbert and Lokemoen 1976, Kirsch *et al.* 1978, Lokemoen *et al.* 1990). Overall, mean visual obstruction was found to be greater at nest sites than at non-nest sites at all scales studied. However, observed differences in use and availability suggest mallards prefer to nest within an intermediate range of cover heights and densities, rather than in the tallest, most dense cover available, and preferences were more pronounced as scale decreased. Mallards avoided very thin cover (e.g. VOR < 1) at all scales studied.

Gotmark *et al.* (1995) demonstrated that song thrushes chose nest sites in vegetation that provided intermediate concealment, and proposed that in many birds, nest site choice may represent a trade-off between concealment of the nest and visibility of the surroundings by the nesting female. Gotmark *et al.* (1995) and D'Eon (1997) also suggest that above an intermediate concealment threshold, predation on eggs and nests does not decrease with increasing cover density and concealment. In mallards, nesting in cover of intermediate height and density may help the female detect and avoid being killed by predators, without consequent increases in the risk of nest and egg loss.

5.4 Variability of vegetation at mallard nest sites

5.4.1 Variation of cover height and density

Vegetation height and density are closely related variables (Robel *et al.* 1970, Higgins *et al.* 1996) and were positively associated at all scales. However, coefficient of variation (CV) of VOR did not differ between nest and non-nest sites, while CV of vegetation height was higher at 4x4 meter nest sites. Further examination of these measures suggests that CV of vegetation height may more readily detect fine scale variation that is important in mallard nest site selection.

In sampling spatial variability, the size or "grain" of the elementary sampling units determines the resolution of the study (Legendre and Legendre 1998), and along with the sampling interval and extent, directly influences the results and their interpretation (Wiens 1981, Wiens 1983). VORs, which were measured every 0.5 meters at the 4 x 4 meter scale, compressed vegetation height and density over a 4 meter line space into an

index value with an inherent resolution of 4 meters. Therefore CV of VOR is a measure

of variation in vegetation height and density at this scale. In contrast, vegetation height

was sampled over the area of a 30 cm disc at 0.5 meter intervals, and CV of vegetation

height estimated variation of the vegetation at a much finer scale. The relative

differences between these fine- and coarse-scale measures of variability indicate that fine

scale heterogeneity in vegetation height and density is preferred by nesting mallards,

while broader scale variation is less important. This is consistent with Hoekman's (1999)

research, which found that mallards and other grassland birds showed a strong preference

for variability in vegetation density at a scale of < 50 cm from the nest.

Autocorrelation analysis of VOR data also indicated that patterns of variation in

vegetation densities were not significantly different between nest and non-nest sites at

broad (16x16 and 32 x 32 meter) scales. VOR data collected at the 4x4 meter scale were

not amenable to autocorrelation analysis, however the resolution of VOR data and its

corresponding capacity to detect fine scale variation in vegetation density is questionable.

Test data demonstrated the capability of autocorrelation analysis to detect and describe

broad scale spatial variation and pattern. Coupling systematic, fine grained sampling of

nest site vegetation with spatial autocorrelation analysis may provide useful information

about fine scale structural patterns in mallard nest site vegetation.

5.4.2 Composition and interspersion of vegetation

 The overall composition and configuration of vegetation at nest sites was more

heterogeneous than in non-nest sites. Preferences for heterogeneity in nest site vegetation

were most strongly expressed at fine scales (e.g. <2m from the nest). At the 4 x 4 meter scale, nest sites had proportionately less grass and more forb and shrub cover, higher diversity indices, and a more interspersed distribution of vegetation types than similar non-nest sites. Vegetation class composition results indicate a non-statistically significant difference in the proportion of shrubs in nest and non-nest sites, while the PHJV habitat class composition results indicate there is significantly more shrubland in nest sites. Differences in the two vegetation classification schemes probably account for this discrepancy: the vegetation class system only recorded shrubs where they were dominant (had the greatest areal cover of all vegetation types present), while the PHJV habitat class scheme recorded shrubland where shrubs had ≥ 30% areal cover. In comparison to the PHJV habitat class system, the vegetation classification scheme "under-represented" shrubs in the composition of nest sites. Since the presence of shrubs is an important nesting habitat characteristic for many birds (Wiens and Rotenberry 1981, Arnold and Higgins 1986, Greenwood *et al.* 1987, Kruse and Bowen 1996), this was an important oversight in the design of the vegetation classification scheme used in the present study.

Diversity index values for nest and non-nest sites did not differ at broader scales (>2 m from the nest). However, the composition and interspersion of vegetation types was significantly more heterogeneous in nest sites than in non-nest sites. As suggested by Klett *et al.* (1988), mallards avoided cropland at broader scales. Nest sites also contained proportionately more "other areas" (primarily roads) at broader scales, perhaps because ditch habitats between bare road beds and adjacent cropland were more heterogeneous

and attractive than other randomly selected sites, or because ditch slopes offered nesting females concealment from predators, while simultaneously offering a view of the surroundings (Gotmark *et al.* 1995). Mallard nest sites are often found < 100 m from wetlands (Bellrose 1979, Kaminski and Weller 1992) but wetlands were not found to be positively associated with nest sites, probably because this habitat preference is expressed at a scale beyond the extent of the present study.

Mallard preferences for fine scale variability in vegetation height and growth form are probably related. As Wiens and Rotenberry (1981) suggest, vegetation structure is derived from plant growth form, and preferences for certain growth forms (e.g. forbs and shrubs) may be driving apparent preferences for vegetation structure(e.g. variability in vegetation height). Greenwood *et al.* (1987) and Kruse and Bowen (1996) have also demonstrated that mallard nests are commonly associated with these growth forms, however Hoekman (1999) found that placement of the nest relative to individual plants contributed more to structural heterogeneity than plant growth form. Vegetation classes used in the present study encompassed plant species with broadly different growth characteristics, ranging from short, sod forming grasses, to bunch grasses, to shrubs and trees. Heterogeneity in nesting vegetation may have been due to the combination of variation in the composition and interspersion of more dissimilar classes of vegetation and habitat, and structural heterogeneity and interspersion of individual plants and similar species within these classes.

5.4.3 Variation of visual obstruction with direction from the nest

Extreme nest microclimates can stress adults and young, and birds appear to place nests in vegetation to moderate nest microclimate (Gloutney and Clark 1997, Hoekman 1999). For example, increased vegetation height and density to the south-west and north-west of the nest may facilitate heat gain in the morning, provide shading against excessive insolation in the afternoon, and provide protection from prevailing westerly winds (Hoekman 1999). At relatively fine scales (<4 meters from the nest), average vegetation densities were higher west of nests than they were east of nests. This pattern probably contributed to higher overall heterogeneity at nests sites.

5.5 Important scales in mallard nest site selection

As described above, mallard nest site preferences are expressed most strongly < 2m from the nest. Hoekman (1999) also found little preference for vegetation characteristics at the scale of the nest patch (10 m from the nest), and concluded that most nest site selection occurs <50 cm from the nest. However, important habitat preferences were detected in this study that affect the overall characteristics of preferred nesting habitat at broader scales. For example, cover was more heterogeneous and mean VOR was greater in nest sites than in non-nest sites at 16x16 and 32x32 meter scales.

5.6 The relationship between vegetation characteristics and habitat attractiveness

At intermediate scales (e.g. 0.6 km^2), correlating the presence or density of breeding birds to some measure of "average" vegetation structure is commonly used to demonstrate general habitat preferences (Rotenberry and Wiens 1980, Hoekman 1999). The Mallard

Model (Johnson 1980) relates the attractiveness of a site for nesting to the mean height and density of the potential nesting habitat, and it predicts that attractiveness increases with mean VOR at intermediate and fine scales (Figure 5.1). Since mean visual obstruction is a measure of central tendency, the Mallard Model inherently assumes that cover attractiveness can be estimated without considering spatial variability.

The results of the present study suggest that attractiveness of various cover heights and densities is scale dependent, and that fine scale preferences for heterogeneity and specific cover heights and densities may be quite important. At broad scales (e.g. 2-16 m from the nest), only very low VORs are avoided, and habitat attractiveness does not appear to significantly increase with cover height and density. At finer scales (e.g. $\leq 2m$ from the nest) mallards appear to prefer a low to intermediate range of cover heights and densities (e.g. VOR 1-5) with high heterogeneity.

Duck nesting use of tall, dense managed cover plots often has been lower than predicted by the Mallard Model (Devries *et al.* 1994). The observed fine-scale nest site preference of mallards may partly explain these discrepancies. Incorporating scale dependent habitat preferences and heterogeneity into models of mallard nest site selection behavior should improve its predictive power and the efficacy of resulting management prescriptions. Since ecological patterns are seldom scale-independent and therefore should not be extrapolated beyond the extent of a given study (Wiens 1989), models of habitat attractiveness should be re-examined in view of this research and the results of broader scale studies such as the PHJV Assessment.
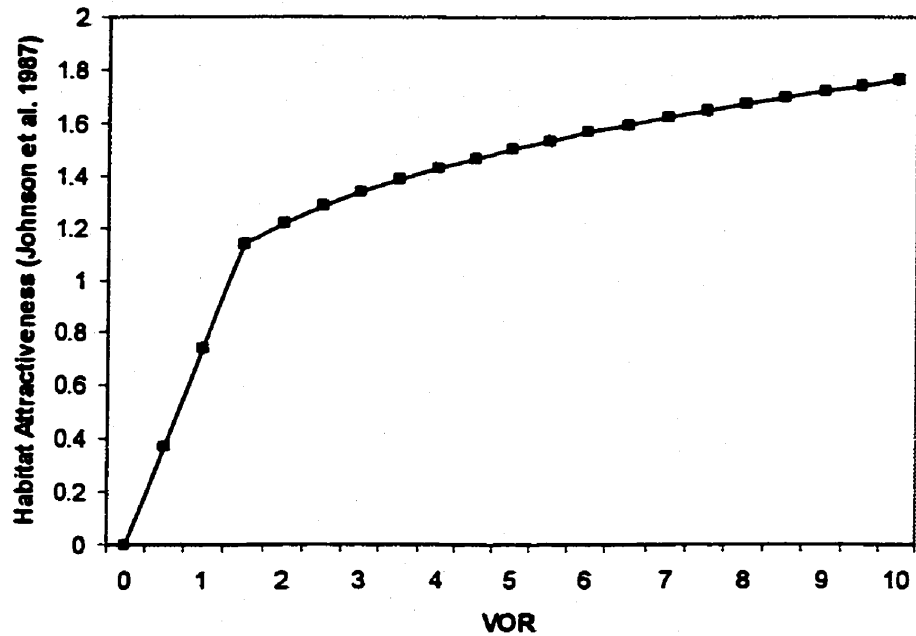
Figure 5.1: Theoretical relationship between VOR and habitat attractiveness used in the Mallard Model (after Johnson *et al.*, 1987)

5.7 Adaptive significance of apparent nest site preferences

As Kaminski and Weller (1996) propose, further research on waterfowl habitat selection

should be directed toward improving understanding of the interrelationships between

habitat selection and nest success so we can more effectively manage waterfowl habitats

and populations. Because reproductive success directly influences fitness, natural

selection should favor choices of nest sites that minimize reproductive failure (Martin

1993), however, as Misenhelter and Rotenberry (2000) suggest, anthropogenic changes in

predator communities and landscapes may have decoupled innate nest site selection

behaviors and patterns of habitat attractiveness from the suitability of preferred habitats.

Further research is needed to resolve uncertainties regarding the influences of

concealment (Gotmark *et al.* 1995, D'Eon 1997) and heterogeneity (Bowman and Harris 1980) on the attractiveness and productivity of various cover configurations.

6.0 SUMMARY AND RECOMMENDATIONS

6.1 Summary of significant results

Nest site preferences are scale dependent, and within the extent of the present study, are most strongly expressed at fine scales (< 2 meters from the nest).

At broader scales (e.g. 2 – 16 meters from the nest), mallards showed a preference for interspersed grasses, forbs and shrubs, avoided cropland, avoided habitats with very low cover height and density, and showed a weak preference for an intermediate to high range of cover heights and densities (e.g. VOR 2 – 5). Overall, mean visual obstruction was higher in nest sites than in non-nest sites at broad scales.

At fine scales (e.g. < 2 meters from the nest), mallards preferred cover with high structural heterogeneity, a low to intermediate range of cover heights and densities (e.g. VOR 1 – 5), and diverse vegetation that included interspersed grasses, forbs and shrubs. Overall, mean visual obstruction was higher in nest sites than in non-nest sites at fine scales.

6.2 Management recommendations

6.2.1 Refining mallard model estimates of habitat attractiveness

Results of this research and other nest site selection studies (e.g. Hoekman 1999) suggest that estimates of habitat attractiveness used in the mallard model should be re-examined. Since mallard nest site selection appears to be scale dependent

and is related to heterogeneity, a hierarchical model of habitat attractiveness that incorporates measures of spatial variability may improve the predictive power of the mallard model and the efficacy of resulting management prescriptions.

6.2.2 The relationship between habitat attractiveness and productivity

Mallard nest site preferences should favor habitats in which they are more successful, however anthropogenic influences may have served to decouple habitat attractiveness and suitability. Further research is needed to resolve uncertainties regarding the influences of concealment, heterogeneity and other cover characteristics on the attractiveness and productivity of various habitats. This information could then be used to inform habitat management decisions and further refine planning tools such as the mallard model.

6.2.3 Setting nesting cover management targets

Management for nesting cover with an intermediate height and density, a high diversity and interspersion of grasses, forbs and shrubs, and fine scale structural heterogeneity may increase its attractiveness to nesting mallards and other waterfowl.

Management efforts to create very tall dense cover are often expensive and not always successful (Devries 2000). Intensive management to increase the height and density of nesting cover may not make it more attractive to nesting mallards and other waterfowl. Management for heterogeneous nesting cover of an intermediate height and density may produce more attractive nesting cover at a lower cost.

6.2.4 Conservation of native areas

Native and naturalized habitats are typically more diverse and heterogeneous than seeded nesting cover. When properly managed, native areas may be more attractive and productive than seeded nesting cover for breeding waterfowl. Results of this study support the idea that heterogeneous remnant native areas should be given high priority for conservation and management as waterfowl nesting cover.

6.2.5 Appropriate measures of fine scale heterogeneity

Because of inherent limits in its resolution, visual obstruction readings may have a limited capability to detect fine scale variation that is important to nesting mallards. Vegetation height was found to be a better measure of variability in vegetation height and density in the present study, and when coupled with techniques such as spatial autocorrelation analysis, would provide useful information about patterns of vegetation structure at waterfowl nest sites.

6.2.6 Designing waterfowl habitat selection studies to facilitate spatial pattern analysis

Waterfowl habitat selection studies are rarely designed to facilitate spatial pattern analysis. Systematic sampling of vegetation characteristics in the present study allowed important spatial patterns to be detected that were missed using aspatial techniques. Since spatial heterogeneity is increasingly being recognized as an important phenomenon in habitat selection by animals, application of spatial sampling and analysis techniques to waterfowl habitat selection studies may provide new and useful information for management of these species.

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