NORTHERN GOSHAWK (*ACCIPITER GENTILIS*) NESTING HABITAT IN NORTHWESTERN CALIFORNIA. AN EXAMINATION OF THREE SPATIAL SCALES: THE NEST AREA, THE POST-FLEDGING AREA, AND THE HOME RANGE

by

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ABSTRACT

Northern goshawk (*Accipiter gentilis*) nesting habitat in northwestern California. An examination of three spatial scales: the nest area, the post-fledging area, and the home range

Timothy T. Weber

The northern goshawk (*Accipiter gentilis*) is a large, forest dwelling raptor that uses a wide variety of habitat types for both nesting and foraging. Due to fire suppression and extensive harvest of mature trees in northwestern California, goshawk nesting habitat has decreased in the region. In addition to forty-nine historic goshawk nest sites, other mature forest patches on several land use types in the coastal region of northwestern California were surveyed. No evidence of breeding goshawks was found within 33 km of the coast. Habitat and topography at goshawk nests found further inland was analyzed at three spatial scales important to breeding goshawks: the nest area (21.5 ha), the post-fledging area (170 ha) and the home range (2110 ha). At the smallest scale, the distance of nests to streams, canopy depth, and Douglas-fir (*Pseudotsuga menzeesii*) trees in the largest size class created the best model to describe nest areas. Using a Geographic Information System to calculate habitat variables at landscape scales, I found that the post-fledging area contained a lower percentage area of Douglas-fir (*Pseudotsuga menzeesii*) in the pole seral stage, a lower percentage area of medium sized *Quercus sp*. overstory, and a greater percentage area of early mature Douglas-fir than at paired random plots. Home ranges contained a

greater percentage area of late mature *Abies sp.*/Douglas-fir forest and a lower percentage area of medium sized Douglas-fir overstory than random plots. As the level of spatial scale increased, the number of significant variables decreased and habitat heterogeneity increased, suggesting that goshawks used nest sites based on smaller scale habitat attributes.

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INTRODUCTION

The northern goshawk (*Accipiter gentilis)* is a large forest raptor that is distributed across northern North America and throughout montane forests in the western United States (Squires and Reynolds 1997). They use a wide variety of structural habitat characteristics for both foraging and nesting. In the eastern U. S., goshawks nested in mature mixed hardwood-hemlock stands of birch (*Betula sp*.), beech (*Fagus sp*.), maple (*Acer sp*.), and eastern hemlock (*Tsuga canadensis*) (Speiser and Bosakowski 1987). In the southwestern U.S., they nested primarily in ponderosa pine (*Pinus ponderosa*) (Reynolds et al. 1992). Younk and Bechard (1994) found goshawks nesting in quaking aspen (*Populus tremuloides*) in northern Nevada, whereas in interior Alaska, goshawks showed a preference for paper birch (*Betula papyrifera*) (McGowan 1975).

Goshawks are forest generalists and use diverse habitat types (Squires and Reynolds 1997). It is a sit-in-wait predator that uses surprise to take medium to large avian and mammalian prey (Squires and Reynolds 1997). They use a mosaic of forested and open areas (Reynolds et al. 1992), edges and dense brush (Johnsgard 1990), recently logged areas, and densely canopied mature stands typical of the nest area (Bier and Drennan 1994, Harghis et al.1994). Goshawks usually have one to several core areas within the home range for nesting and for foraging (Kennedy et al. 1994). Goshawk nest sites were usually found in mature to old growth stands composed of larger trees of greater density than the surrounding forest, and were frequently associated with meadows, riparian habitats or other natural openings (Speiser and

Bosakowski 1987, Reynolds et al. 1992, Allison 1996). Mature forest stands used by nesting goshawks provided dense canopy cover and were often found on gentle to moderately steep slopes with east-to-northerly aspects (Moore and Henny 1983, Hall 1984, Speiser and Bosakowski 1987, Hayward and Escano 1989, Reynolds et al. 1992, Younk and Bechard 1994, Bull and Hohmann 1994, Allison 1996).

In California, goshawks breed from the southern Cascade Range through the Sierra Nevada, Klamath and Warner Mountains. In northern California, due to a lack of monitoring, the current distribution of goshawks is not fully understood. According to the United States Fish and Wildlife Service (1998) "in the North Coast Ranges province, reduction in the amount of late successional forest, increased vegetation density in managed forest, and short harvest rotation schedules have likely resulted in a reduction of local goshawk populations." In the coastal ranges of northern California, only 12 goshawk nests have been documented via informal surveys, pre-timber species inventories, or by local birders (Woodbridge 2000, personal communication). Coastal surveys in similar habitat types in Oregon discovered two breeding pairs in 1995 (Thraikill and Andrews 1996), although no evidence of breeders was found previously (DeStefano and McCloskey 1997).

Population status and the purported decline in goshawk numbers is controversial in the western U.S., however, organizations have petitioned to list the goshawk as threatened under the Endangered Species Act (ESA). Some scientists have agreed that goshawk populations and reproduction may be declining in western North America, primarily due to overharvest of timber and human disturbance (Reynolds et al. 1982, Moore and Henney 1983, Crocker-Bedford and Chaney 1988), while others have

determined that there is insufficient evidence to indicate a range contraction or a decline in numbers in western North America (Kennedy 1997, United Fish and Wildlife Service 1998). Additionally, other than Hall's (1984) research on Six Rivers National Forest, there is little current information relative to goshawk breeding presence in northern California. Thus, the uncertain population status of goshawks combined with the lack of information regarding breeding goshawks supported the need for goshawk surveys in the coastal ranges of northern California.

The post-fledging area (PFA ~ 170 ha) (an area used by juvenile goshawks learning to fly and hunt), and the home range (HR ~ 2110 ha) are landscape scale areas found to be important to breeding goshawks (Reynolds et al. 1992), and can vary in size due to geographic location and forest size (Squires and Reynolds 1997). For example, telemetry studies in southeastern California (Harghis et al. 1994) found that nearly all birds incorporated areas as far as 3.5 km from the nest into their home ranges. In eastern forests, Bosakowski and Speiser (1994) showed that landscape features such as the distance to paved roads and human habitation, and not just nest stand characteristics, were important considerations when managing smaller forests for breeding populations of goshawk.

It was hypothesized that coastal nests would be found in small pockets of habitat similar to inland nest sites (i.e., mature trees, dense canopy cover, and a sparse shrub layer). Due to the consistency of specific nest site attributes shown in the literature (Reynolds et al. 1992, Penteriani 2002), small scale habitat characteristics would be more important for breeding goshawks than would be landscape scale habitat characteristics. Nest sites were compared to random plots to illuminate patterns of

habitat and topographic variables at three different spatial scales surrounding active goshawk nests. The questions posed in this study were two fold: first, do goshawks still nest in the coastal region of northern California, and secondly, do they use nest sites randomly or are there specific habitat and topographic patterns at various spatial scales that are common to all nest sites?

STUDY AREA

Goshawk nest surveys were conducted from March through August of 2001-2002 in five counties of northwestern California: Del Norte, Humboldt, Mendocino, Sonoma and Trinity (Appendix A). Due to size and habitat diversity, the study area was divided into three land use types: coast range habitat on timber company property, coast range habitat that was no longer being harvested, and inland/upland habitat managed by public natural resource agencies.

In northwestern California, logging companies maintaining harvest cycles between 40-60 years (Dill 2001, personal communication) have eliminated many of the older, mature trees in the region, although some of the last remaining old-growth stands have been preserved as habitat for the northern spotted owl (*Strix occidentalis caurina*). Based on previous goshawk detections (Dill 2000, Woodbridge 2000, personal communications), mature and old growth redwood and Douglas-fir stands owned by Pacific Lumber Company and Mendocino Redwood Company were surveyed. Although there was no old growth forest on Mendocino Redwood Company's property, one historical nest site and approximately 160 hours were spent surveying numerous mature forest stands for breeding goshawks.

Within the coastal belt dominated by timber company lands, several national and state parks, Bureau of Land Management lands and a nature preserve (Angelo Coast Nature Preserve) were surveyed. Old growth characteristics can still be found in the Headwaters Preserve, Redwood National Park, and Humboldt Redwoods State Park. Redwoods were the dominant overstory species in the coast range. Other mixed conifer

components included Douglas-fir, sitka spruce (*Pinaceae picea*), and Red cedar (*Thuja plicata*) (Hickman 1993). Redwood forest transitioned into Douglas-fir forest as fog and moisture levels dropped, soils changed, and distance from the Pacific Ocean increased (Hickman 1993). The understory was composed of smaller mixed hardwoods including oaks (*Quercus spp*.), California bay (*Umbellularia californica*), madrone (*Arbutus menzeesii*), red alder (*Alnus rubra*), and big-leaf maple (*Acer macrophyllum*). The shrub layer was composed of huckleberry (*Gaylussacia spp*.) and ferns (*Pteridium spp.*) (Zinke 1977).

Surveys were conducted on the Six Rivers National Forest, which was composed of approximately 404,686 hectares of primarily coniferous and hardwood forests, and located within the Northwestern California Geographic Region of the California Floristic Province (Hickman 1993). The forest included portions of the Coast Range and the Klamath and Siskiyou Mountains. Available moisture and varying temperatures were reflected in the vegetation. Coast redwoods (*Sequoia sempervirens*) were the dominant forest type near the Oregon border, and ponderosa pine prevailed on the east side and southeast corner of the forest (Jimerson 1993).

Six Rivers National Forest ranges from 30-2450 m in elevation, and is drained by the Smith, Klamath, Trinity, Mad, Van Duzen and Eel Rivers. Six Rivers National Forest is oriented along a northwest to southeast axis. Abrupt changes in topography are common, and slopes range from 0 to 95% (Jimerson et al. 1996).

Distribution of forest types that dominate Six Rivers National Forest was largely determined by elevation, available moisture and parent material (Jimerson 1993). Vegetation below 1000 m was characterized by canyon live oak (*Quercus chrysolepis)*

on the dry, rocky, steep canyon sites, and tanoak (*Lithocarpus densiflora*) at the bottom of slopes up to approximately 1000 m elevation. Higher elevation montane sites above 1000 m were dominated by white fir (*Abies concolor*), red fir (*Abies magnifica*), and mountain hemlock (*Tsuga mertensiana*) (Franklin and Dyrness 1973). Douglas-fir replaced tanoak on dryer slopes above 700 m elevation and continued upslope to approximately 1400 m elevation; White fir replaced Douglas-fir on cooler slopes above 1200 m, and red fir (*Abies magnifica*) replaced white fir at the top of the highest mountains (usually above 1900 m elevation). Port-Orford cedar (*Chamaecyparis lawsonia*) was located along stream bottoms, and small pockets of Jeffrey pine (*Pinus jeffreyi*) were found between 500-1550 m elevation on soils derived from serpentine parent material. Oak woodlands (*Quercus garryana* and *Quercus kelloggii*) and grasslands were dispersed throughout the drier southern portion between 700-1500 m. Other species commonly found in this region included gray pine (*Pinus sabiniana Dougl.*), various manzanitas (*Arctostaphylos sp*.), dogwood (*Cornus spp*.), hazlenut (*Corylus spp.)*, ceanothus (*Ceanothus spp.*) (Griffin 1988), and pockets of grasslands (Sawyer et al. 1977).

METHODS

Goshawk nest survey areas were based on a database of historic goshawk sightings and nest sites compiled by Woodbridge (2000 personal communication). Eight nests or sighting locations in the coastal belt of northern California were examined for goshawk. Three historic nests were located on tree farming property, two on Bureau of Land Management property and private land, two in state parks and one in the Angelo Coast Nature Preserve.

The low density of breeding goshawks in the Coast Ranges necessitated enlarging the study area to include known populations of breeding goshawks. Therefore, 48 historic nest sites were surveyed on Six Rivers National Forest.

To guide surveys (apart from historical nest sites) in Humboldt Redwoods State Park and Six Rivers National Forest, a map representing an index of "optimal" nesting habitat was developed using ArcView GIS (Table 1). The index was based on habitat attributes common in other goshawk studies (Hayward and Escano 1989, Speiser and Bosakowski 1987). A vegetation data layer was used to incorporate tree size and type, seral stage, percentage canopy cover, and distance to water into the index. Numerical values were assigned to these attributes and totaled, and a map representing the index (Table 1) was created. Seral stage definitions used throughout this study are located in Appendix B (Jimerson 2002, personal communication).

Table 1. An index of optimal northern goshawk nesting habitat using attributes in the Six Rivers National Forest GIS vegetation data layer of northern California. Variables were chosen based on what the literature deemed to be important to breeding goshawks. Each variable was assigned increasing values which correlated to the importance of that variable in the nest areas of breeding goshawks.

Variable	Distance to stream	Size class (dbh)	Seral Stage	% Canopy cover	Index value
	>400 m	0-28.0 cm	Shrub, pole	0-25%	0
	200-400 m	28.1-53.0 cm	Early mature	26-50%	1
	0-200 m	>53.0 cm	Late mature/ OG	51-75%	2
	-	-	-	76-100%	3
					Index totals
Minimum variable value=less optimal habitat	0	0	0	0	0*
Maximum variable value=most optimal habitat	2	2	2	3	9**

*0 score: if all variables were received values of 0, it would result in the least optimal habitat
**9 score: The maximum value possible (all variables 2 or 3), indicates optimal habitat

Dawn acoustical surveys were conducted during February and March of 2002 (Woodbridge 2000), coinciding with the onset of pair formation and copulation, to detect courting goshawks near nests. “Listening stations” were established near historic nest stands or potential suitable habitat, and beginning at sunrise, listening periods of up to three hours (Penteriani 1999) were conducted.

Broadcast acoustical surveys were conducted during the nestling and fledgling period to elicit responses from unmated, territorial adults, breeding adults, and juveniles in accord with Kennedy and Stahlecker (1993). Calling stations were placed 200 - 300 m apart on parallel transects that passed through nest stands or potential nesting habitat. Adjacent, parallel transects were spaced no more than 300 m apart, and the call stations on adjacent transects were offset by 150 m to ensure complete coverage of the area. An area with an 800 m radius around the original nest was surveyed.

Stand searches were conducted to follow up on goshawk responses, or to survey historical nest stands and potential nesting habitat. One to three surveyors walked 25 m transects to ensure that all potential nest trees within the area in question were surveyed.

To determine the activity status of a nest site, protocol required two surveys per breeding season for two successive years. Due to logistical, financial, and temporal constraints, 43 historic nest stands were surveyed only once per breeding season. Other historic nest stands that had undergone significant change due to timber harvest or fire, or did not fit the general description of a goshawk nest stand depicted in the literature (Hayward and Escano 1989, Reynolds et al. 1992, Speiser and Bosakowski 1987) were

surveyed just once in 2001. Special attention was given to nest stands where a goshawk response was recorded. They were surveyed in both years, but not always twice within one breeding season. If a goshawk responded to a broadcasted call, that forest stand was intensively searched until a nest was located. If no nest was found after a stand search, the area was revisited later in the breeding season to detect fledglings. If a nest was still not located in 2001, it was surveyed again in 2002.

A nest was classified as active if goshawks were detected in the vicinity of a large stick nest accompanied by the presence of adult or juvenile goshawks, or obvious signs of breeding goshawks and their young, such as recent white-wash, plucking posts, and goshawk feathers (Woodbridge 2000). Habitat and topographic variables were measured around goshawk nests at three spatial scales: the nest area (r=21.5 m, 0.145 ha), the post-fledging area (PFA) (r=735 m, 170 ha), and the home range (HR) (r=2600 m, 2110 ha). The variables in the nest area (Tables 2, 3) were measured using standard forestry techniques and were based on studies by Speiser and Bosakowski (1989) and Hayward and Escano (1989). A nest tree was the tree that was occupied by a nest and active breeding pair of goshawks during at least one of the two years of the study.

To measure canopy cover, ground cover, and understory, a 50-m measuring tape was laid in the four cardinal directions. Measurements were recorded at 5 m intervals for ground cover and the presence or absence of understory. A spherical densitometer was used to calculate canopy cover at 10 m intervals. One final value for canopy cover was calculated by averaging the 20 measurements. Ground cover was divided into four categories: downed-woody debris, duff, grasses or forbs, and shrubs. Downed-woody

Table 2. Definitions of small scale habitat and topographical variables measured using standard forestry techniques at northern goshawk nests and center trees at paired random plots in northwestern California, 2001-2002.

Variable	Definition	Method of measurement
Nest height (m)	Height from uphill side of nest tree to bottom of nest	Triangulation using range finder, meter tape, (m) and clinometer (deg)
Nest exposure (deg.)	Direction that middle of nest mass faces	Compass; See table below
Number of branches supporting the nest	A count of the major branches that support the nest structure	Visually with binoculars
Nest tree (species)	Tree species that houses nest	Visual identification
Nest tree dbh	Diameter of tree at breast height	Metal dbh tape
Nest tree height (m)	Distance from base (uphill side) of tree to top of crown	Triangulation using range finder (m) and clinometer (deg)
Canopy height (m)	Distance from base (uphill side) of tree to live green branches	Triangulation using range finder (m) and clinometer (deg)
Canopy depth (m)	Maximum overstory height – minimum overstory height	Subtraction
Condition of nest tree	Is it live or dead (snag)?	Visual interpretation
Elevation (m) at nest tree	The elevation at the base (uphill side) of nest tree	Altimeter within Global Positioning System (GPS)
Slope (deg.) at nest tree	Angle of hill side	Clinometer
Slope aspect (deg.) at nest tree	Direction that the hill side faces	Compass

Table 3. Definitions of habitat and topographical variables measured in the area surrounding the nest (21.5 m radius) and paired random plots in northwestern California, 2001-2002.

Variable	Definition	Method of measurement
Tree types (Species)	All trees identified to species	Visual identification
Tree density	Number of trees/plot, trees/ha	Visual identification; number of trees within plot radius (0.145 ha), then extrapolated to ha
Mean tree height (m)	Mean height of randomly selected tree from each cardinal quadrant	Triangulation using range finder (m) and clinometer (deg)
Mean canopy height (m)	Mean canopy height of randomly selected tree from each quadrant (n =4)	Triangulation using range finder (m) and clinometer (deg)
Mean canopy depth (m)	Mean maximum overstory height – mean minimum overstory height	Triangulation using range finder (m) and clinometer (deg)
dbh (cm)	Diameter at breast height	Metal dbh tape
Canopy cover (%)	Average percentage of canopy obscuring vertical view at measuring point	Densiometer measurements at 10-m intervals for 50 m in the cardinal directions centered on the nest tree
Understory (%)	Layer of canopy beneath and not part of the overstory canopy layer	Percentage of understory canopy present at 10-m intervals for 50 m in the cardinal directions centered on the nest tree
Aspect (deg.)	North: 337.6º - 22.5º Northeast: 22.6º - 67.5º East: 67.6º - 112.5º Southeast: 112.6º - 157.5º South: 157.6º - 202.5º Southwest: 202.6º - 247.5º West: 247.6º - 212.5º Northwest: 212.6º - 337.5º	Compass

debris was considered any dead wood greater than 10 cm in diameter and longer than 1 m. Duff was any dead plant material or dead wood smaller than downed-woody debris. Grasses or forbs were defined as any non-woody plants. Any woody plant less than 2 m tall was classified as a shrub. Understory was classified as the presence or absence of a second layer of trees that were at least 2 m tall, but not part of the taller, main canopy layer. Tree height, canopy height, and canopy depth were calculated by averaging the measurements of four randomly chosen trees within the nest plot, one from each quadrant (Table 3). To determine which tree was to be chosen from each quadrant, a random number generator (Microsoft Excel, Microsoft Co.) produced a direction (1-360º) and a distance (1 -22 m) from the nest tree, and the closest tree to the random point was used to measure tree height and canopy height.

Landscape variables were analyzed using ArcView 3.2 GIS software (Environmental Systems Research Institute, Inc., 1992-1999). A set of concentric circular plots was established around the six active nests in Six Rivers National Forest. ArcView GIS was used to measure habitat and topographic characteristics at two spatial scales (Reynolds et al. 1992), the PFA, and the HR .The PFA is used by immature goshawks learning to fly and hunt before they disperse at approximately 10-15 weeks post-fledge. The HR incorporates all habitat usages by breeding pairs such as roosting, foraging, and bathing areas. According to Lehmkuhl and Raphael (1993) “the circular plots do not necessarily represent goshawk space-use, but they can be reasonably unbiased estimates for raptors.”

The percentage area of each habitat variable was determined using a vector based vegetation data layer created for Six Rivers National Forest (Jones 2001,

personal communication). The vegetation data set was used exclusively for the GIS analysis because the majority of goshawk activity was in Six Rivers National Forest (six of the eight nests and all four territories), and data layers containing habitat data surrounding the other two nests were less detailed than, and incompatible with the Six Rivers National Forest data layer. The creation of the Six Rivers National Forest vegetation coverage included the development of polygon overlays that were digitized into the ARC/INFO geographic information system (ESRI 1993). Due to the inherent error involved in digitizing fuzzy-boundary vegetation communities (Wilkie and Finn 1996), accuracy cannot be determined beyond whole number percentages. Elements mapped and subsequently analyzed included existing vegetation type, seral stage, overstory tree size class (Jimerson et al. 1996, Jimerson 2001, personal communication, Appendix B), and canopy cover. The Six Rivers National Forest vegetation data layer was also used to calculate several habitat cover classes, as well as the distances of "center" trees to streams. A 30 m Digital Elevation Model (DEM) of northern California was used to calculate elevation. Nest site coordinates were recorded at the nest tree using a Garmin 12XL global positioning system (GPS) (+/- 6 m) and were co-registered with the other GIS layers using Universal Transverse Mercater (UTM) coordinates.

Historic nest sites were paired with a control (non-nest site), which was determined using a random point generator downloaded from the ESRI website. The following two criteria were used to determine a valid control site: 1) points could not be located in non-habitat (i.e., water or sites with no trees), and 2) points had to be located outside the nest stand (12.1 ha, radius = 196 m), but within the larger area of the

goshawk's home range (2110 ha, 2600 m) (Reynolds et al. 1992). Each non-nest or control site was located using a GPS with the random coordinates, and the largest tree that was closest to the randomly chosen coordinates was used as the "nest", or center tree. Habitat and topographic attributes at random sites were measured exactly as the nest site.

A 1-1 matched-pair logistic regression analysis (Hosmer and Lemeshow 1989) was used to compare habitat variables measured at nest sites with those at random sites. A 1-1 matched-pair logistic regression works on the differences between nest site variables and the control, rather than on the original values of the variables as in a normal logistic regression. Data from 2001 and 2002 were pooled for an overall 1-1 matched-pair logistic regression model.

To begin the model selection process, a univariate 1-1 matched-pair logistic regression analysis was conducted on each independent variable using S+ statistical software (Mathsoft Inc. 1998-1999). Variables that were significant at the 0.25 level were included in the initial model. The more traditional alpha value of 0.05 was not used because this may exclude biologically important variables (Hosmer and Lemeshow 1989). Correlation matrices were used to detect multicollinearity. If independent variables were strongly correlated ($r > 0.60$), one was removed from the analysis. The most biologically important variable based on literature consensus or the one with the lowest P-value was retained. Models were obtained using stepwise logistic regression and comparing Akaike's Information Criteria (AIC) values for the full and reduced models. Model stability was assessed by examining the standard error values

between the reduced and full models. Large changes in standard error indicated unstable models (Hosmer and Lemeshow 1989).

RESULTS

Eight active goshawk nests and four territories were found in Humboldt, Sonoma, and Trinity counties of northwestern California in 2001 and 2002. Nest heights ranged from 13.7 m to 35.4 m, and nests were supported by two to six distinguishable branches. Nest exposure varied greatly with mean exposure southwesterly (Table 4, Appendix C).

Small scale habitat characteristics: nest vs. random sites

Nest trees were significantly taller with a greater dbh, and had deeper canopies than the center trees at random plots (Table 4). Although the onset of the canopy was several meters higher at nest trees, canopy height was not significantly higher (Table 4) than at random center trees. Nest areas were significantly different from random plots for the following variables: mean tree height, mean canopy height, mean canopy depth, percentage canopy cover and percentage of understory presence (Table 4).

The topography surrounding nests was also significantly different from random plots. Seven of eight nest areas were on hillsides that faced north or northeast (344º - 61º), and one faced southeast (126º) whereas random plots were located on southeasterly facing slopes (Table 5, Appendix C). Nest trees were significantly closer to streams and at a lower elevation than random plots (Table 5). The percentages of ground cover classes in the nest area were not significantly different than random plots (Appendix D). Live stem, total stem, and snag densities were greater at random plots than nest areas but none were significant (Appendix E). There was nearly twice the

Table 4. Comparison of habitat variables goshawk nest areas (n=8) and paired random plots, northwestern California, 2001-2002. Circular plots (0.145 ha) extended 21.5 m radius around center trees and random plots were within the home range (2600 m), but > 196 m from an active nest. Each variable was compared individually using a 1:1 matched-pair logistic regression. P-values < 0.25 were considered for inclusion in the final model.

	Nest area			Random plots			
Variable	Mean (%)	SE (%)	Range (%)	Mean (%)	SE (%)	Range (%)	*P*
Nest or Center Tree							
Nest height (m)	25.0	2.8	13.7, 35.4	NA*			
No. of nest support branches	4.0	0.40	2.0, 6.0	NA*			
Nest exposure (deg.)	208.5	5.0	56.0, 346.0	NA*			
Center tree dbh (cm)	114.0	17.8	55.9, 189.2	61.9	11.6	24.1, 111.0	<0.001
Center tree height (m)	51.1	4.2	36.3, 70.0	30.3	4.8	16.0, 50.0	0.003
Canopy height (m)	25.9	3.2	13.7, 39.6	18.7	3.8	33.5, 149.8	0.128
Canopy depth (m)	25.3	2.7	8.2, 18.7	11.6	2.1	2.0, 21.9	<0.002
Center Tree Plot: 21.5 m radius around center tree							
Mean tree height (m)	32.4	1.8	25.1, 39.6	17.8	3.2	8.4, 32.1	0.005
Mean canopy height (m)	128.3	1.1	14.2, 24.5	12.1	2.1	4.4, 22.5	0.014
Mean canopy depth (m)	14.1	1.2	8.2, 18.7	6.5	1.2	2.8, 11.4	<0.001
Canopy cover (% 50m radius)	81.6	5.8	73.5, 88.2	72.5	4.2	53.3, 90.3	0.034
Understory (% presence, 50 m radius)	24.5	7.5	0.0, 40.0	12.2	6.3	0.0, 33.3	0.030

* Not Applicable: the center tree is the "nest" tree on random plots

Table 5. Comparison of topographical characteristics in goshawk nest areas (n=8) and paired random plots, northwestern California, 2001-2002. Circular plots (0.145 ha) extended 21.5 m radius around center trees and random plots were within the home range (2600 m), but > 196 m from an active nest. Each variable was compared individually using a 1:1 matched-pair logistic regression. P-values < 0.25 were considered for inclusion in the final model.

Variable	Nest area			Random plot			*P*
	Mean (%)	SE (%)	Range (%)	Mean (%)	SE (%)	Range (%)	
Slope (%)	44.3	6.2	21.3, 68.0	43.2	5.3	20.9, 69.0	0.86
Slope aspect (deg.)	24.7	42.5	2.0, 350.0	132.9	99.5	32.0, 328.0	0.05*
Distance to stream (m)	232.9	65.6	15.0, 546.0	522.4	65.6	255.0, 835.0	0.005
Elevation (m)	891.2	55.9	552.0, 1058.0	969.8	86.3	470.9, 1236.0	0.04

*P-value for two sample testing of angles

density of stems at random plots (Appendix E). There was twice the density of large conifers and a significantly greater density of "huge" conifers in nest areas compared to random plots (Appendix F). Random plots were composed of a significantly greater density of *Quercus sp.* of all size classes, except for the "huge" size class (Figure 1, Appendix F). There was a significantly greater density of miscellaneous medium-sized hardwoods on random plots compared to nest areas (Figure 1, Appendix F).

The univariate analyses indicated that many of the aforementioned variables were candidates for inclusion in the multivariate model, including the density of large *Abies sp.*, *Quercus sp.* of all size classes, tree height, canopy height and depth, percentage canopy cover, downed woody debris, live stem density and dbh of live stems, distance to streams, and elevation (Tables 3-5, Figure 1, Appendices D-F). While significant, center tree variables were excluded from the multivariate analysis, because they represented only one tree. Variables that represented the mean of four trees better characterized the goshawk's nesting area, and, therefore were used in the multivariate analysis (e.g., it would be expected that a mature Douglas-fir would be significantly different from a randomly selected oak tree). However, center tree variables were useful to illuminate the difference between a nest tree and a randomly selected tree.

The 1-1 matched-pair logistic regression model indicated that goshawk nest areas were closer to streams, and displayed greater canopy depth and a greater percentage area of *Abies sp.* with dbh greater than 91.0 cm compared to random plots (Table 6).

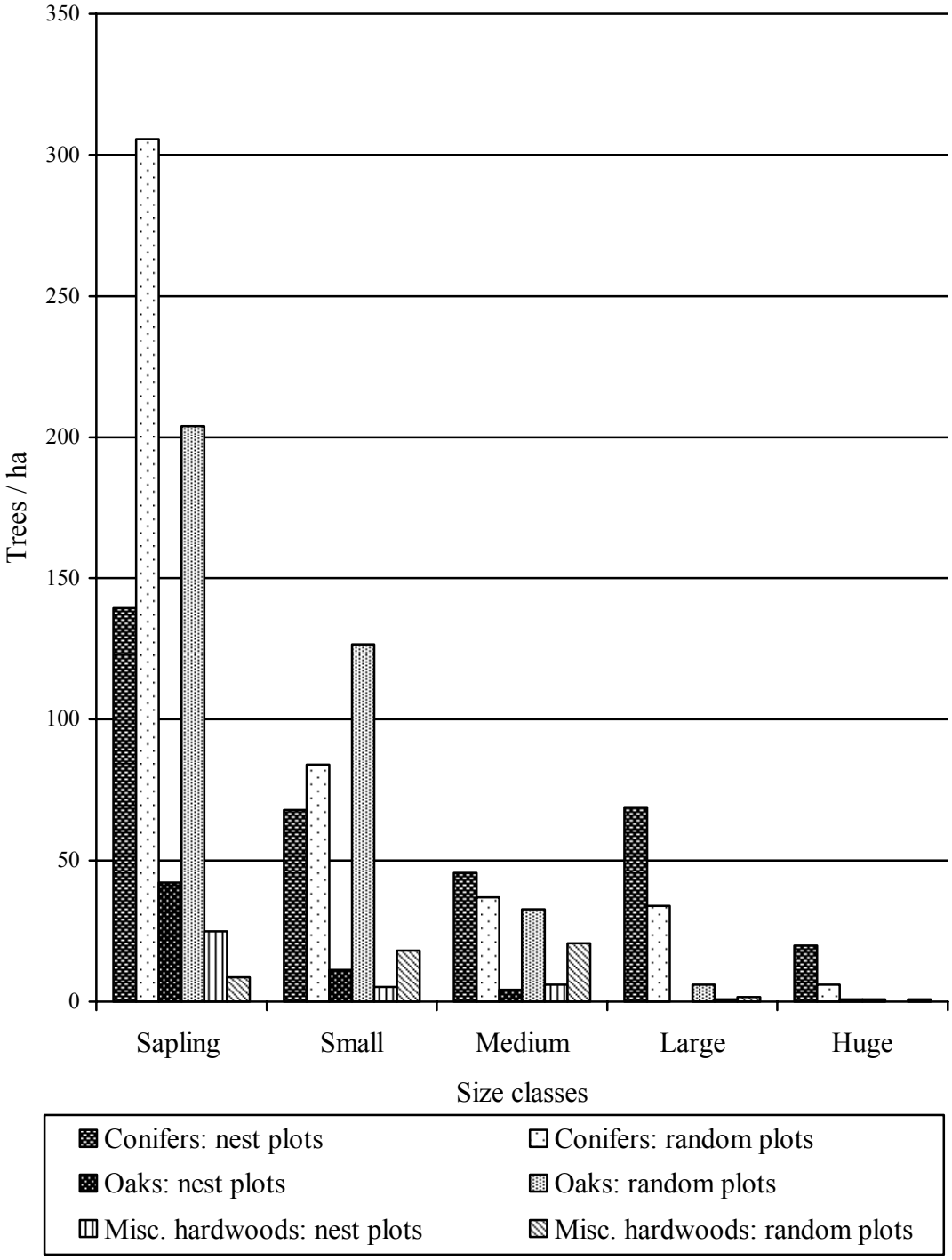

Figure 1. Tree densities (stems/ha) divided into specific size classes at active goshawk nest areas and paired random plots in northwestern California, 2001-2002. Circular plots (0.145 ha) extended 21.5 m around center trees and random plots were within the home range (2600 m), but > 196 m from an active nest.

Table 6. Summary of mean differences (±SE) at nest areas (n=8) compared to random plots (0.145 ha) for habitat and topographical variables of goshawks in northwestern California, 2001-2002. Values are the results of a multivariate logistic regression (MPLR) model.

Variable	Mean difference	Coefficient	Wald X^2	*P*
Distance to stream (m)	-289.5 ± 75.6	-0.02	8.0	<0.01
Canopy depth (m)	7.6 ± 2.0	1.2	3.0	0.08
Abies sp. and Douglas-fir.: Size class 5 dbh > 91.0 cm	13.8 ± 4.1	0.2	>0.01	0.98
Model[a]			11.0	

[a] Model AIC (Akaike's Information Criterion) = 6.0.

GIS ANALYSIS: The home range and the post–fledging area

In Six Rivers National Forest, the post-fledging area (PFA), was composed entirely of Douglas-fir and *Quercus sp.* There were no forest stands dominated by *Abies sp.* or *Pinus sp.* within 735 m of the nest. In the PFA, there was a significantly greater percentage area of early mature Douglas-fir (Table 7).

Random plots contained a significantly greater percentage area of Douglas-fir in the open canopy cover class (PFA: 4 ± 4, random 8 ± 5, P = 0.04, df = 5, Appendix 7) and a significantly greater percentage area of *Quercus sp.* in the closed canopy cover classes (PFA: 2 ± 1, random 13 ± 2, P = 0.04, df = 5, Appendix 7), than PFA's. The only significantly different seral stage in the PFAs was early mature Douglas-fir (PFA: 24 ± 5, random 17 ± 5, P = 0.02, df = 5, Table 7). There were no significant differences in size classes at PFAs and paired random plots (Appendix 8). The 1-1 matched-pair logistic regression analysis found that the PFA consisted of a greater percentage area of Douglas-fir in the early mature seral stage, a lower percentage area of Douglas-fir in the pole seral stage, and a lower percentage area of medium sized *Quercus sp.* than random plots (Table 8).

Regarding the home range, there was a greater percentage area of A*bies sp.* in all seral stages except for the shrub stage (Table 9). However, only the percentage area of late mature/old growth *Abies sp.* was considered for model inclusion (Table 9). The random plots had a greater percentage area of *Quercus sp.* in all seral stages, but none were significant and only early mature *Quercus sp.* was considered for inclusion in the final

Table 7. The mean percentage area of tree species in each seral stage in the post-fledging area (PFA=170 ha) around active goshawk nests (n=6) and paired random plots, northwestern California, 2001-2002. The random plot centers were within the active HR, but > 196 m from the nest, and the area of tree species in each size class was based on the total area of the PFA equaling approximately 100%. The data layer was created for Six Rivers National Forest, 2001. Conifer composition was entirely Douglas-fir. Each variable was compared individually using a 1:1 matched-pair logistic regression, and P-values < 0.25 were considered for inclusion in the final model.

Seral stage	Plot	Tree species: *Pseudotsuga menzeesii* Mean (%)	SE (%)	Range (%)	*P*	*Quercus sp.* Mean (%)	SE (%)	Range (%)	*P*
Shrub	PFA	3	2	0, 14	0.38	0	0	0, 0	-
	Random	5	3	0, 17		0	0	0, 0	
Pole	PFA	3	2	0, 11	0.23	1	1	0, 5	0.30
	Random	4	2	0, 11		8	8	0, 48	
Early Mature	PFA	24	6	7, 47	0.02	4	4	0, 22	0.18
	Random	17	5	4, 36		2	2	0, 10	
Mid-mature	PFA	32	8	2, 52	0.26	2	1	0, 7	0.13
	Random	35	7	10, 52		8	5	0, 30	
Late Mature/ Old growth	PFA	24	12	4, 74	0.71	0	0	0, 0	-
	Random	21	5	1, 33		0	0	0, 0	

Table 8. Summary of mean differences (±SE) of percentages between the post-fledging area (PFA=170 ha) at active goshawk nest sites (n=6) and paired random plots for habitat variables included in the multivariate logistic regression (MPLR) model to describe PFA habitat of goshawks in Six Rivers National Forest, northwestern California, 2001-2002.

Variable	Mean difference (%)	Coefficient	Wald X^2	*P*
Douglas-fir: Pole seral stage	-1.0 ± 1.0	7.7	1.5	0.2
Douglas-fir: Early mature seral stage	7.4 ± 2.2	1.7	6.9	0.01
Quercus sp.: Size class 3 dbh=28.1-53.0 cm	-5.6 ± 4.0	-1.6	0.01	0.9
Model[a]			8.3	

[a] Model AIC (Akaike's Information Criterion) = 6.0.

Table 9. The mean percentage area of the major tree species in each seral stage in the home range (HR=2110 ha) surrounding active goshawk nests (n=6) and paired random plots, northwestern California, 2001-2002. The random plot centers were within the active HR, but > 196 m from the nest. The area of tree species in each seral stage was based on the total area of the HR equaling approximately 100%. The GIS vegetation data layer was created for Six Rivers National Forest, 2001. Each variable was compared individually using 1:1 matched-pair logistic regression and P-values < 0.25 were considered for inclusion in the final model.

Seral stage	Plot	Tree species: *Abies sp.* and Douglas-fir Mean (%)	SE (%)	Range (%)	*P*	*Quercus sp.* Mean (%)	SE (%)	Range (%)	*P*	*Pinus sp.* Mean (%)	SE (%)	Range (%)	*P*
Shrub	HR	5	2	1, 15	0.83	0	0	0, 0	0.38	0	0	0, 0	0.01
	Random	5	3	1, 17		0	0	0, 0		0	0	0, 0.2	
Pole	HR	4	1	2, 7	0.48	2	2	0, 10	0.35	0	0	0.0, 0.0	-
	Random	4	1	1, 6		3	2	0, 15		0	0	0.0, 0.0	
Early Mature	HR	27	2	20, 32	0.67	7	2	0, 12	0.10	1	1	0.0, 4.1	0.04
	Random	27	2	21, 32		8	2	1, 14		1	1	0.0, 3.0	
Mid-mature	HR	23	2	18, 30	0.89	5	3	0, 20	0.26	0	0	0.0, 1.5	0.60
	Random	23	2	19, 28		6	3	1, 14		1	0	0.0, 1.0	
Late Mature/ Old growth	HR	18	6	4, 43	0.15	0	0	0, 0	0.24	0	0	0.0, 0.0	0.24
	Random	17	5	4, 38		0	0	0, 0		0	0	0.0, 0.2	

model (Table 9). The shrub and early mature seral stages of *Pinus sp.* were significantly different compared to random plots and considered for model inclusion (Appendix H). There was no discernible difference in the percentage area of the four canopy cover classes at HR's compared to random plots (Appendix I). Only the percentage area of "large" *Abies sp.* in the HR approached significance (HR: 37 ± 6, random 35 ± 5, P = 0.07, df = 4, Appendix J). Random plots contained a significantly greater percentage area of small oaks (HR: 8 ± 2, random 9 ± 2, P = 0.07, df = 4, Appendix J) compared to HR's.

The 1-1 matched-pair logistic regression model calculated that the variables that best described the difference between the HR and random plots were a greater percentage area of late mature *Abies sp.* and a lower percentage area of *Abies sp.* in the medium size class (Table 10).

Table 10. Summary of mean differences (±SE) of percentages between the home range (2110 ha) at active goshawk nest sites (n=6) and paired random plots for habitat variables included in the multivariate logistic regression (MPLR) model to describe home ranges of goshawks in Six Rivers National Forest, northwestern California, 2001-2002

Variable	Mean difference (%)	Coefficient	Wald X^2	*P*
Abies sp. and Douglas fir: Late-mature seral stage	1.4 ± 1.0	0.6	1.5	0.2
Abies sp. and Douglas-fir: Size class=medium, dbh=28.1-53.0 cm	-0.4 ± 0.3	0.2	1.0	0.6
Model[a]			2.5	

[a] Model AIC (Akaike's Information Criterion) = 6.01

DISCUSSION

Eight historic goshawk sites in the coastal range of northern California and 48 other nest sites further inland were surveyed on several different land use types: timber company property, national Forest Service lands, Beareau of Land Management, National Park Service, State Parks and the Angelo Coast Nature Preserve. No active goshawk nests or conclusive evidence that any goshawks were nesting at historic sites in the coastal ranges of northwestern California were found. The active nest closest to the coast was found on the Angelo Coast Nature Preserve in northern Sonoma County, California. The Angelo Coast Nature Preserve is approximately 33 kilometers from the Pacific Ocean where coastal redwoods transition into more xeric Douglas-fir and mixed-oak habitat typical of inland northern California. Although it was harvested historically, it was no longer exposed to timber extraction. The nest stand was located in a mature Douglas-fir stand, as were the other seven nests located approximately 100 kilometers away in Six Rivers National Forest.

Western populations of breeding goshawks nested in various forest types including pines, firs, and aspens. The eight goshawk nests in this study were all found in mature Douglas-fir trees, which was consistent with several studies (Hall 1984, Siders and Kennedy 1996, Squires and Ruggiero 1996). As in many North American goshawk studies, nest areas in Six Rivers National Forest were found in mature to old growth stands composed of larger trees of greater density than the surrounding forest, (Speiser and Bosakowski 1987, Reynolds et al. 1992, Allison 1996). Additionally, the 1-1 matched-pair logistic regression showed that the nest area was composed of

significantly greater densities of Douglas-fir trees in the largest size class compared to random plots, and goshawks always nested in one of the largest trees of the stand. These results are similar to those reported from in Montana (Squires and Ruggiero 1996), and Europe (Penteriani and Faivre 1997). Five of the eight nests were found in forest stands that had been selectively harvested, indicating mature trees were retained from the previous forest stand. These "predominants" may have accounted for the disparity between the nest tree height compared to the mean tree height of the nest stand (Table 4). It was possible that these "predominants" were selected by breeding goshawks as they were taller with a greater dbh than most of the trees in the nest stand. Or, they simply functioned as the nest tree, but influenced nest heights in a small sample. Regardless, large, mature trees were positively correlated with greater tree heights and dbh, dense canopy cover and canopy depth.

The 1-1 matched-pair logistic regression indicated that canopy depth was also an important variable to describe differences between nest areas and random plots, which corroborates Finn's (2001) finding that canopy depth was an important correlate of nesting habitat. It is important to note that in Six Rivers National Forest, nests were placed against the trunk and at or just above the onset of the forest canopy as seen in Oregon (Reynolds et al. 1982), Wyoming and Idaho (Squires and Ruggiero 1996), New Jersey (Speiser and Bosakowski 1987), and California (Hall 1984). Two hypotheses supported the correlation of goshawk occupancy and canopy depth. First, Crocker-Bedford and Chaney (1988) found that this nest position could benefit from the microclimatic features found at the base of the overstory canopy (Geiger 1966). A deep canopy can serve as a protective umbrella from precipitation or direct sunlight (Newton

1979), resulting in cooler temperatures. Secondly, a deep canopy provided a screening cover and limited access from avian nest predators, such as great horned owls (*Bubo virginianus*) (Reynolds et al. 1982), red-tailed hawks (*Buteo jamaicencis*), or ravens and crows (*Corvus sp*.).

Goshawk nest trees were significantly closer to streams than random plots. Several studies agreed that goshawks nested in the proximity of free water, whether it was an ephemeral stream, major river, or pond (Reynolds et al. 1982, Hall 1984, Harghis et al. 1994). The function of nesting close to a water source is not understood, and although it is common amongst breeding goshawks, it is not a habitat requirement (Reynolds et al. 1992, Speiser and Bosakowski 1987). In eastern California, Harghis et al. (1994) found that water sources influenced the configuration and shape of the home range, and goshawks incorporated water sources into their home ranges from as far away as 3.5 km. Waterways were commonplace in Six Rivers National Forest. Therefore, one must be cautious interpreting this type of data. It may just be a reflection of the region's landscape and topography and not important as a single characteristic. However, Kennedy (1988) suggested that "stable" environments were important nest site conditions, and Siders (1995) confirmed the preference for cooler conditions around nests. Not only were nest areas closer to streams in Six Rivers National Forest, they were at lower elevations on north facing slopes and within stands of large, mature trees with deep canopies. This should have increased the stability of microclimatic conditions around goshawk nests, reducing exposure to wind, precipitation, and vast temperature fluctuations.

Seven of the eight pairs in this study nested on north facing slopes which was common to many studies where goshawks avoided warmer temperatures on southerly facing slopes (Hall 1984, Speiser and Bosakowski 1987, Reynolds et al. 1992, Younk and Bechard 1994, Bull and Hohman 1994, Penteriani and Faivre 1997), except in Alaska (McGowan 1975, Titus et al. 1994), and high elevation nest sites in Arizona (Crocker-Bedford and Chaney 1988). Penteriani (2002) proposed that aspect exposure seemed to be latitude and temperature dependant. These studies lend strength to the pattern that goshawks chose nest sites based, at least partially, on microclimatic conditions.

PFAs in Six Rivers National Forest contained a significantly greater percentage area of early-mature Douglas-fir, a lower percentage area of mid-mature Douglas-fir, and equal percentages of late mature/old growth Douglas-fir than random plots (Table 7). Goshawks often select mature seral stages for nesting (Speiser and Bosakowski 1987, Reynolds et al. 1992, Allison 1996, Finn 2001, Finn et al. 2002). All mature seral stages are relatively similar in forest structure and are used intensively by goshawks, even though they may vary in age, height, dbh, and height to live canopy (Appendix B). They contain relatively lower stem densities then earlier seral stages, and typically maintain a closed and deep canopy. Due to the goshawks large size, higher stem densities may limit the goshawks ability to fly through smaller trees located in early seral stages (e.g. shrub and pole). Although early mature stands were made up of smaller trees than later seral stages, nearly 81% of trees in the PFA were at least "medium" sized. Only 11% of the PFAs total area was composed of trees in the smallest size class. Additionally, the 1-1 matched-pair logistic regression indicated that

goshawks used PFAs with a lower percentage area of pole seral stage Douglas-fir, and a lower percentage area of medium sized *Quercus sp.* The absence of smaller Douglas-fir and *Quercus sp.* exemplified goshawks' use of larger stands of mature conifers (Squires and Reynolds 1997), whether for the larger flyways used by immature birds learning to fly and hunt (Daw and DeStefano 2001), foraging grounds for adult birds (Beier and Drennan 1997), or nesting. The greater percentage area of mature trees and absence of pole seral stages in PFAs suggested that habitat structure at larger scales was important for goshawks in Six Rivers National Forest.

The 1-1 matched-pair logistic regression model found that the important differences between goshawks' HR and random plots were a greater percentage area of late mature *Abies sp.*, and a lower percentage area of medium sized *Abies sp*. The greater percentage area of late mature *Abies sp.* is consistent with studies that found late mature forest to be an important component of not only the nest area, but at landscape scales (Reynolds et al. 1992, Beier and Drennan 1997, Finn 2001, Finn et al. 2002) as well. The habitat differences associated with increasing spatial scale indicated a general trend towards increased habitat diversity. Although all three spatial scales contained high percentages of mature forest, goshawks in Six Rivers National Forest used a greater percentage area of mature Douglas-fir in the nest area, and at the landscape scale of the PFA. However, at the scale of the HR, habitat diversity increased dramatically, and few variables were significantly different compared to random plots.

Landscape scale summary of the HR and PFA

On average, the 170 ha PFA was composed almost entirely of Douglas-fir forest, and a small percentage area of *Quercus sp.* (Table 9, Appendices H-I). Comparatively, the habitat in the HR was more diverse as expected when examining an area as large as 2100 ha. which experiences large fluctuations in topography and elevation. Nearly 70% of the general vegetation types contained in the entire Six Rivers National Forest vegetation data set were present in the HR. The increase in habitat diversity in the HR included increases in *Pinus sp.*, *Quercus sp*. (black oak and canyon live oak), *Abies sp.* (red and white fir), and vegetation in riparian areas (*Salix sp.* and *Alnus sp*.). Interestingly, the percentage area of chaparral and non-vegetation components, such as rock outcroppings, cliff bands, quarries and mines, and streams and ponds comprised approximately 6% of both the PFA and HR. Harghis et al. (1994), Younk and Bechard (1994), and Daw and DeStefano (2001) considered wet and dry openings important parts of goshawk territories, whether for travel corridors or important sources of prey (Daw and DeStefano 2001). Although wet openings were not considered a habitat requirement, Daw and DeStefano (2001) speculated they may contribute to higher densities of breeding goshawks.

Mature Douglas-fir made up 81% of PFAs and 68% of HRs. This was similar to nest sites in Washington that were surrounded predominantly by late seral forest, (60 – 75% of the landscape surrounding nests at all scales measured) (Finn 2001, Finn et al. 2002). However, breeding goshawks in Washington were most responsive to land cover in the stand initiation phase (e.g., young and regenerating clearcuts). Occupancy was unlikely if stand initiation cover exceeded 20% of the home range and 10% of the PFA

(Finn 2001, Finn et al. 2002). This could be compared to Six Rivers National Forest where the shrub seral stage, analogous to stand initiation cover in Finn et al.'s (2002) study, covered just 4.9 % of goshawks' HR, and only 3.2 % of PFAs.

Although Six Rivers National Forest has been harvested historically, many hectares of contiguous early, mid-, late, and old growth forest seral stages still remained in the southernmost Mad River District where six of the eight nests and four non-breeding goshawks were found. Douglas-fir forest covered 52% of the entire Mad River district, and 42% forest stands were composed of trees greater than 28.0 cm dbh and 60% canopy cover. Comparatively, 81% of PFAs were made up of mature (mid-, late, and old growth) Douglas-fir forest, 46% of those trees were greater than 53.1 cm dbh, and 64% of the total canopy cover was " dense" canopy. The presence of mature Douglas-fir forest was negatively correlated with mature *Quercus sp*., which composed just 7% of PFA's. The absence of other habitat types could have been a reflection of the species composition at varying elevations, slope and aspect, or available groundwater. Or, it might reveal goshawks' preference for the attributes of mature Douglas-fir forest within the PFA. These attributes include the vegetation (higher, deeper canopy, lower stem density), microclimate (cooler, more "stable", north facing slopes), and prey availability. Obviously, a study which was able to measure reproductive success of goshawks in multiple habitat types would illuminate discussions regarding the selection and quality of specific habitat and topography at multiple spatial scales.

Management Recommendations

Reynolds et al. (1992) put forth management recommendations for goshawk and forest management in the southwestern United States. Their recommendations were supported by DeStefano et al. (2006) for the Pacific northwest region. Their recommendations called for various Vegetation Structural Stages (Reynolds et al. 1992), and are applicable, generally, to many forests including Six Rivers National Forest. They recommended that the forest be managed for specific vegetation structural stages to provide a mix of cover types for goshawks and their prey, and to promote old growth development and replacement.

The nest area is a key component of goshawk home ranges. I recommend maintaining mature Douglas-fir forest stands within 300 m of permanent streams or rivers, especially on north-facing slopes, to encourage new breeding sites. At historic nest sites, a minimum of 12 ha areas (Reynolds at al. 1992) with a high density of large conifers with a dense and deep canopy should be maintained. The preservation of large patches of mature forest and the maintenance of forest stands that will develop into mature seral stages around historic nests should increase the likelihood of breeding pairs in Six Rivers National Forest. It is important to maintain patches of mature conifers rather than tanoak because a low percentage of ground cover is actually a product of mature Douglas-fir forest in that it lacks a consistent mid-layer of hardwoods and supports a one-tiered overstory (Jimerson et al. 1996)

Mature patches of conifers should also be present throughout the PFA and the HR as goshawks will use them for foraging as well as nesting (Beier and Drennan 1997). They are especially important in the PFA as young birds are learning to fly and

hunt. Prey should be abundant in the PFA, and other forest types that encourage the productivity of goshawks' major prey species, typically medium sized birds such as Steller's jays (*Cyanocitta stelleri*), northern flickers (*Colaptes auratus*), American robins (*Turdus migratorius*), and mammals such as squirrels (*Sciurus sp.*), hares (*Lepus californicus*) and rabbits (*Sylvilagus bachmani*). Additionally, small pole-sized trees should be intermixed with mature trees to increase cover for hunting and feeding on or near the ground.

Six Rivers National Forest, at least in the Mad River District, is composed of a mosaic of habitat types and structural stages, and supported a population of breeding goshawks. A detailed analysis of the other districts would provide insight into the lack of breeding pairs discovered therein. Of significant importance to breeding goshawks would be the presence of dry and wet openings (e.g., meadows, riparian areas) for travel corridors and foraging areas, mature patches of conifers for additional breeding opportunities and foraging events, and specific habitat structure to increase populations of several prey species. A detailed analysis of the goshawk's major prey species and their respective habitats would provide an overview of the structural stages needed to effectively manage the forest to increase the productivity of breeding goshawks.

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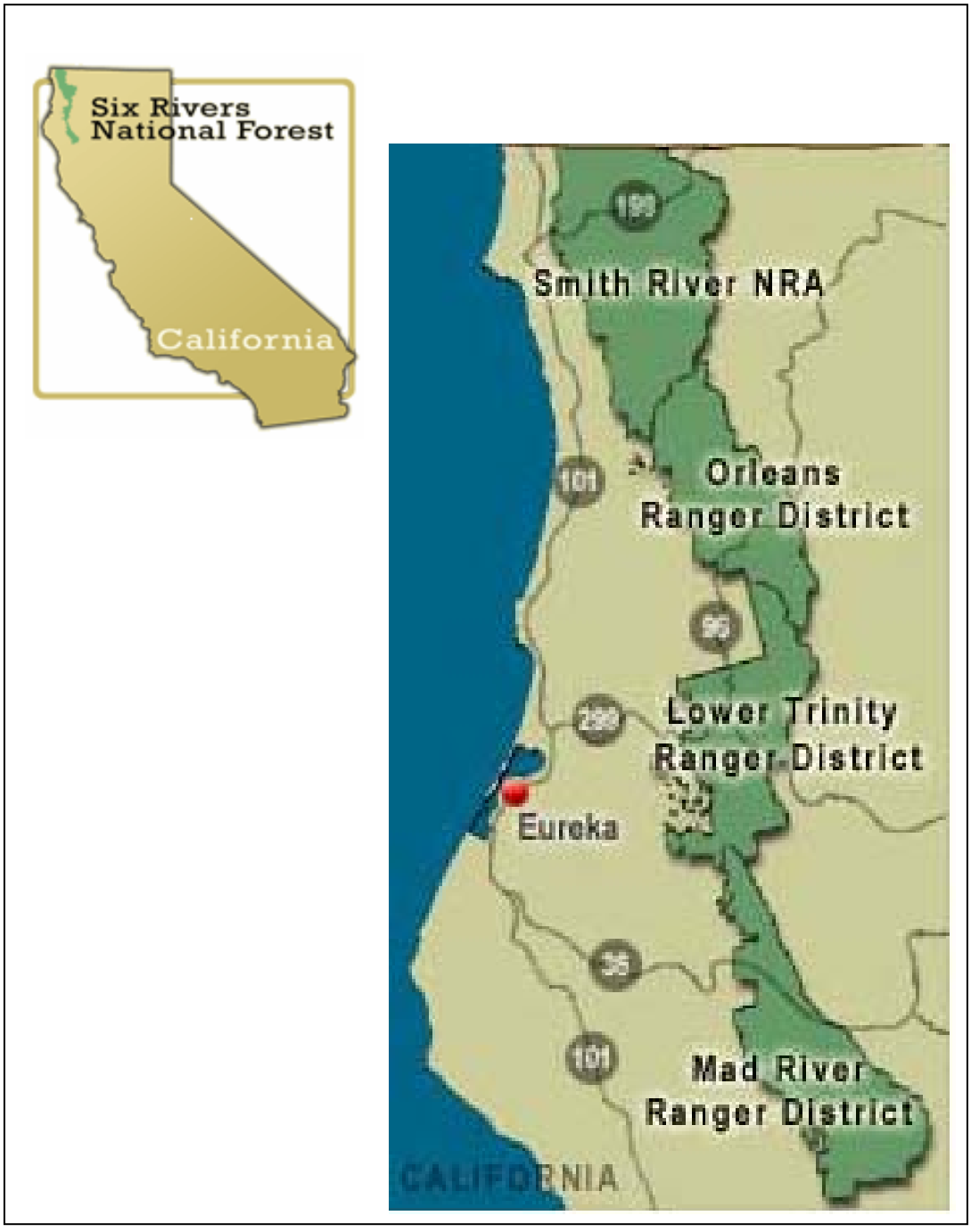
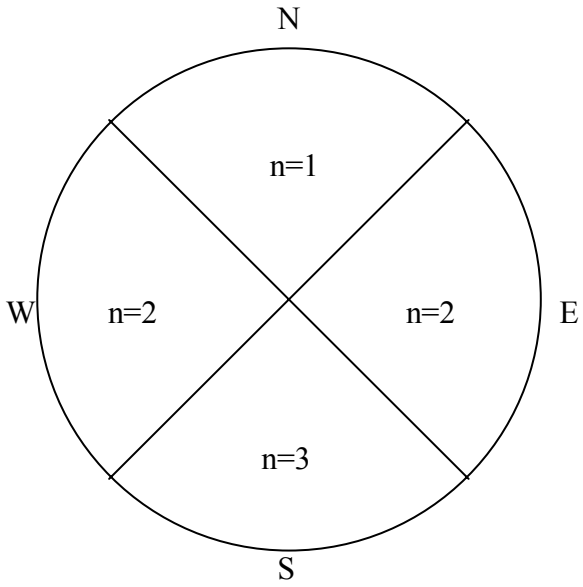


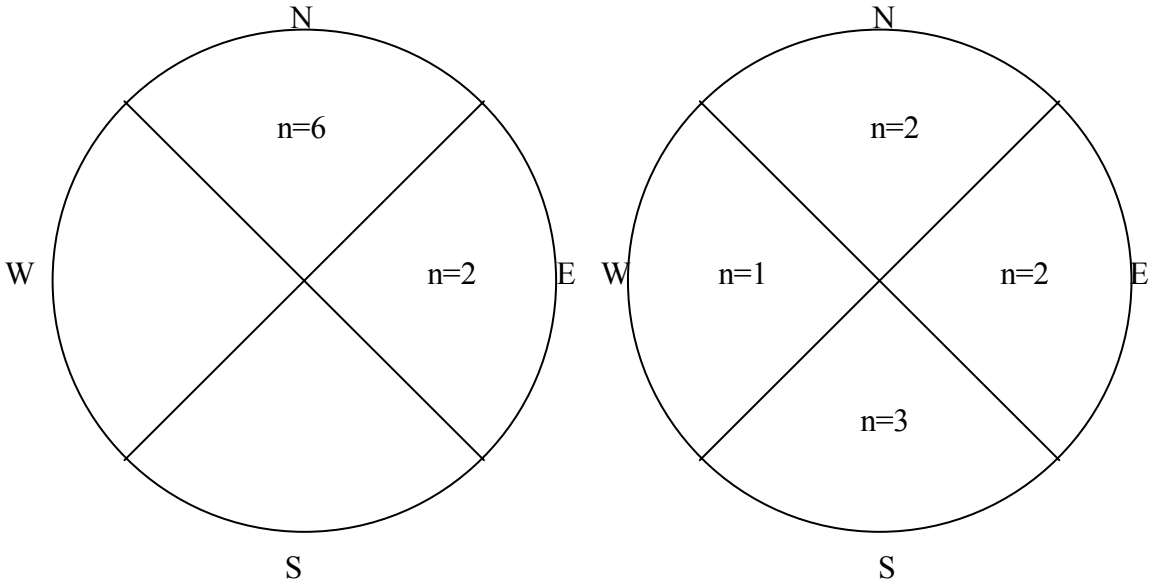
Appendix A. Six Rivers National Forest, northwestern California. Six nests and four territories were found in the Mad River District, Humboldt County, 2001-2002. Figures obtained from Six Rivers National Forest, 2006.

Appendix B. Descriptions of the seral stages for the GIS vegetation data layer constructed by Six Rivers National Forest, northwestern California, and classified by Jimerson (Personal communication 2001).

Shrub	Generally open stands dominated by shrubs with the top layer of conifers < 15.1 cm dbh that have resulted from timber harvest or high intensity disturbance such as wildfire, mass soil movement, or flood. These stands shift from a dominance of shrubs throughout most of the stage to one dominated by trees in the latter part of the stage.
Pole	Generally dense, single layer stands, dominated by trees, with the top layer of conifers ≥ 15.1 cm dbh and < 28.0 cm dbh, that have resulted from timber harvest, or high intensity disturbance such as wildfire, mass soil movement, or flood. Shrub and herb layer are lacking or non-existent
Early mature	Generally dense, closed canopy, single layer stands, dominated by trees with the top layer ≥ 28.0 cm dbh and <53.0 cm dbh. Shrub and herb layer are lacking or non-existent
Mid-mature	Generally dense, closed canopy stands, with one or two layers, dominated by trees with the top later of conifers ≥ 53.1 cm dbh and < 91.0 cm dbh. Shrub and herb layer of low cover. First appearance of large snags (> 50 cm dbh). Vertical and horizontal diversity lacking.
Late mature	Generally dense, closed canopy stands, with two or more layers present, dominated by trees with the top layer of conifers ≥ than 91 cm dbh. Shrub and herb layer beginning to increase in cover. Snag density increases with large snags (> 50 cm dbh) as a standard component.
Old Growth	Generally open to dense, with multiple layers, dominated by trees of various size classes, the top layer usually > 91 cm dbh. Shrub and herb layer apparent, vertical and horizontal diversity high, snag and log density high and composed of snags and logs > 50 cm dbh.



Nest Exposure



Nest sites Hillside Aspects Random Sites

Appendix C. Nest exposure (deg) and hillside aspect (deg) at active goshawk nest sites (n=8), and hillside aspect at paired random plots, northwestern California, 2001-2002. Random plots were within the home range (2600 m) but > 196 m from the nest.

Appendix D. Comparison of ground cover characteristics in goshawk nest areas (n=8) and paired random plots, northwestern California, 2001-2002. Circular plots (0.145 ha) extended 21.5 m radius around center trees and random plots were within the home range (2600 m), but > 196 m from an active nest. Each variable was compared individually using a 1:1 matched-pair logistic regression.

	Nest site			Random plot			
Variable	Mean	SE	Range	Mean	SE	Range	*P*
% Duff	60.9	6.0	27.5, 82.5	68.1	7.7	30.0, 90.0	0.44
% Grass	14.4	4.0	2.5, 37.5	12.9	6.6	0.0, 50.0	0.83
% Downed woody debris	18.4	3.8	2.5, 37.5	13.0	2.0	5.0, 20.0	0.18
% Shrub	6.3	2.7	0.0, 22.5	5.9	2.2	0.0, 20.0	0.93

Appendix E. Comparisons of average stem densities and tree diameters at breast height (dbh) in goshawk nest areas (n=8) and paired random plots, northwestern California, 2001-2002. Circular plots (0.145 ha) extended 21.5 m around center trees and random plots were within the home range (2600 m), but > 196 m from an active nest. Each variable was compared individually using a 1:1 matched-pair logistic regression.

	Nest areas			Random plots			
Variable	Mean (%)	SE (%)	Range (%)	Mean (%)	SE (%)	Range (%)	*P*
Number of live stems / plot	60.5	9.6	(33.0, 112.0)	118.4	33.1	(22.0, 282.0)	0.07
Mean dbh (cm) of live stems/plot	33.1	4.1	(17.8, 54.4)	24.7	4.0	(11.9, 48.2)	0.18
Number of snags / plot	7.5	1.7	(2.0, 16.0)	11.6	4.1	(0, 31.0)	0.20
Mean dbh (cm) of dead stems per plot	22.3	4.9	(8.8, 51.0)	13.3	2.8	(0.0, 25.0)	0.17
Total stems (live + dead) / plot	68.0	9.9	(35.0, 117.0)	130.0	36.6	(30.0, 305.0)	0.07
Mean dbh (cm) of total stems/plot	31.5	3.7	(17.9, 50.4)	23.5	3.3	(11.9, 41.5)	0.15

Appendix F. Stem density (stems/ ha) comparison of oaks, conifers, and miscellaneous hardwoods divided into specific size classes in goshawk nest areas (n=8) and paired random plots, northwestern California, 2001-2002. Circular plots (0.145 ha) extended 21.5 m radius around center trees and random plots were within the home range (2600 m), but > 196 m from an active nest. Each variable was compared individually using a 1:1 matched-pair logistic regression.

		Size Class														
		Sapling (2.54 -15.0 cm)			Small (15.1 – 28.0 cm)			Medium (28.1 – 53.0 cm)			Large (53.1 – 91.0 cm)			Huge (>91.0 cm)		
Tree type		Mean (%)	SE (%)	P (%)	Mean (%)	SE (%)	P (%)	Mean (%)	SE (%)	P (%)	Mean (%)	SE (%)	P (%)	Mean (%)	SE (%)	P (%)
Conifers	Nest	139.4	63.6		68.0	10.4		45.6	13.1		68.9	13.5		19.8	3.5	
				0.15			0.63			0.60			0.12			<0.01
	Random	305.6	188.8		84.0	36.2		37.0	7.8		34.0	11.9		6.0	1.6	
Quercus sp.	Nest	42.2	17.6		11.2	4.7		4.3	2.2		0.0	0.0		0.9	0.9	
				0.16			0.02			0.02			0.04			0.02
	Random	204.0	112.9		126.5	71.6		32.7	11.6		6.0	3.3		0.9	0.9	
Big leaf maple, dogwood, hazelnut, madrone	Nest	25.0	15.7		5.2	2.5		6.0	3.5		0.9	0.9		0.0	0.0	
				0.30			0.18			0.02			0.65			0.24
	Random	8.6	5.0		18.1	9.6		20.7	10.7		1.7	1.7		0.9	0.9	

Appendix G. The mean percentage area of tree species in each canopy cover class in the post-fledging area (PFA=170 ha) around active goshawk nests (n=6) and paired random plots, northwestern California, 2001-2002. The random plot centers were within the active HR, but > 196 m from the nest, and the area of tree species in each size class was based on the total area of the PFA equaling approximately 100%. The data layer was created for Six Rivers National Forest, 2001. Conifer composition was entirely Douglas-fir. Each variable was compared individually using a 1:1 matched-pair logistic regression.

		Tree species							
Canopy closure (%)	Plot	Douglas-fir			*P*	*Quercus sp.*			*P*
		Mean (%)	SE (%)	Range (%)		Mean (%)	SE (%)	Range (%)	
Open (0-25%)	PFA	4	4	0, 21	0.04	1	1	0, 5	0.58
	Random	8	5	0, 31		2	8	0, 10	
Sparse (26-50%)	PFA	3	1	0, 8	0.15	4	3	0, 22	0.14
	Random	2	1	0, 6		0	2	0, 2	
Dense (51-75%)	PFA	15	8	2, 49	0.33	0	0	0, 1	0.10
	Random	10	5	0, 33		2	0	0, 13	
Closed 76-100%)	PFA	64	8	45, 92	0.79	2	1	0, 6	0.04
	Random	62	7	43, 84		13	2	0, 48	

Appendix H. The mean percentage area of tree species in each size class in the post-fledging area (PFA=170 ha) around active goshawk nests (n=6) and paired random plots, northwestern California, 2001-2002. The random plot centers were within the active HR, but > 196 m from the nest, and the area of tree species in each size class was based on the total area of the PFA equaling approximately 100%. The data layer was created for Six Rivers National Forest, 2001. Conifer composition was entirely Douglas-fir. Each variable was compared individually using a 1:1 matched-pair logistic regression.

Size class dbh	Plot	Tree species: Douglas-fir Mean (%)	Douglas-fir SE (%)	Douglas-fir Range (%)	*P*	*Quercus sp.* Mean (%)	*Quercus sp.* SE (%)	*Quercus sp.* Range (%)	*P*
Small (2.54-28.0 cm)	PFA	6	3	0, 14	0.16	6	4	0, 22	0.54
	Random	9	5	0, 28		10	8	0, 48	
Medium (28.1-53.0 cm)	PFA	35	10	7, 65	0.07	2	1	0, 7	0.12
	Random	27	8	13, 63		8	5	0, 30	
Large (>53.1 cm)	PFA	46	9	17, 76	0.92	0	0	0, 0	-
	Random	45	8	9, 63		0	0	0, 0	

Appendix I. The mean percentage area of the major tree species in each canopy cover class in the home range (HR=2110 ha) surrounding active goshawk nests (n=6) and paired random plots, northwestern California, 2001-2002. The random plot centers were within the active HR, but > 196 m from the nest. The area of tree species in each canopy cover class was based on the total area of the HR equaling approximately 100%, and the GIS data layer was created for Six Rivers National Forest, 2001. Each variable was compared individually using 1:1 matched-pair logistic regression.

Canopy cover (%)	Plot	Tree species: *Abies sp.* and Douglas-fir Mean (%)	SE (%)	Range (%)	*P*	*Quercus sp.* Mean (%)	SE (%)	Range (%)	*P*	*Pinus sp.* Mean (%)	SE (%)	Range (%)	*P*
Open (0-25%)	HR	6	3	1, 18	0.97	2	1	0, 4	0.70	0	0.2	0, 1	0.87
	Random	6	3	1, 20		2	1	0, 4		0	0.2	0, 1	
Sparse (26-50%)	HR	5	0.5	4, 7	0.09	6	3	0, 18	0.43	1	0.5	0, 3	0.04
	Random	5	0.5	4, 7		6	3	0, 17		1	0.4	0, 3	
Dense (51-75%)	HR	21	4	9, 38	0.64	4	1	0, 8	0.03	0	0.2	0, 1	0.32
	Random	21	4	9, 38		5	1	1, 9		0	0.0	0, 0	
Closed (76-100%)	HR	45	6	28, 71	0.16	3	1	0, 9	0.28	0	0.0	0, 0	0.24
	Random	44	6	30, 66		3	2	0, 14		0	0.0	0, 0	

Appendix J. The mean percentage area of the major tree species in each size class in the home range (HR=2110 ha) surrounding active goshawk nests (n=6) and paired random plots, northwestern California, 2001-2002. The random plot centers were within the active HR, but > 196 m from the nest. The area of tree species in each size class was based on the total area of the HR equaling approximately 100%. The vegetation data layer was created for Six Rivers National Forest, 2001. Each variable was compared individually using 1:1 matched-pair logistic regression and P-values < 0.25 were considered for inclusion in the final model.

Size class DBH	Plot	Tree species: *Abies sp.* Mean (%)	SE (%)	Range (%)	*P*	*Quercus sp.* Mean (%)	SE (%)	Range (%)	*P*	*Pinus sp.* Mean (%)	SE (%)	Range (%)	*P*
Small (2.54-28.0 cm)	HR	9	3	3, 21	0.93	8	2	1, 12	0.07	0	0.1	0, 1	0.47
	Random	9	3	3, 23		9	2	2, 15		0	0.2	0, 2	
Medium (28.1-53.0 cm)	HR	31	3	21, 41	0.22	6	3	0, 20	0.75	1	0.6	0, 4	0.21
	Random	31	3	22, 41		6	3	0, 23		1	0.4	0, 3	
Large (>53.1 cm)	HR	37	6	22, 63	0.07	0	0.1	0, 1	0.10	0	0	0, 0	0.53
	Random	35	5	23, 58		0	0.1	0, 1		0	0	0, 0	