IMPACTS OF SCALE ON BREEDING BALD EAGLES, (*Haliaeetus leucocephalus*), ALONG THE HUDSON RIVER, NEW YORK

A Final Report of the Tibor T. Polgar Fellowship Program

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ABSTRACT

For the first time in over 100 years, bald eagles have successfully nested along the Hudson River, New York. In the interest of protecting and promoting this population, the New York State Dept. of Environmental Conservation recently initiated a study concerning the ecology of the Hudson River eagle population. One important and often overlooked component of species habitat requirements is the spatial distribution of resources, and how this distribution is viewed by the study animal. In order to define the 'eagle-centered perspective' regarding specific resources, we attempted to identify the scale at which the eagles showed the strongest selection for or against habitat features. Habitat features considered were selected on the basis of historical eagle research, and included water depth, human activity, and canopy structure.

Between 26 March and 15 July 1999 we intensively monitored three bald eagle breeding pairs along the Hudson River. Eagles were monitored by boat, and perch and forage locations were mapped on enlarged 1:12,000 aerial photos. These points were then compared to GIS coverages of each of the above habitat features. For each feature, the coverage scale was varied by systematically varying first the grain (cell size) and extent (landscape considered). Differences in grain selection were analyzed using chi-squared analysis and related confidence intervals. Extent selection was quantified using landscape analysis methods.

For water depth, eagles showed strong selection for areas that were exposed at low tide at a 75-meter grain and 150-meter extent. For human activity, eagles showed strong selection for areas of low, but not non-existent, human activity at a 400-meter grain, with no apparent extent influence. For canopy structure, eagles showed a decrease in selection at grains greater than 75 meters, and showed high selection at a 200-meter extent for landscapes with large patches of open area, correlating to forest areas bounding marshes or tidal flats. For each habitat feature, the combination of grain and extent selected define the scale at which eagles show the greatest degree of habitat selection. Research conducted at these scales may be the most effective approach to managing breeding bald eagle habitat along the Hudson River Corridor. Due to the low sample size and untested methods, these results must be interpreted cautiously until supported by additional research.

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INTRODUCTION

For the first time in the twentieth century, bald eagles have naturally recolonized the Hudson River Corridor (HRC) and successfully fledged young. This can be attributed to several factors, but primarily to an aggressive reintroduction program by the New York State Department of Environmental Conservation (NYSDEC) in other parts of the state (P. Nye, personal communication, April 1998). However, many threats still face this expanding population. Over the last 100 years, the landscape of the Hudson Valley has changed drastically, and the suitability of the remaining habitat may be questionable due to extensive development and heavy traffic, both commercial and recreational. While much information exists concerning eagle ecology, there is a significant gap in understanding the importance of the spatial distribution of resources across a landscape.

Fundamental to the determination of how resource distribution affects the viability of bald eagle habitat is an understanding of how eagles view the landscape, or what is referred to as their perception of 'scale'. Scale includes two important components; *grain* and *extent*, both of which influence the ability of researchers to perceive and interpret ecological patterns. Grain refers to the size of individual units of observation, minimum mapping unit, or 'resolution' of a study (Wiens 1989, Frair submitted). As the grain of an investigation is increased, the observed heterogeneity of a landscape decreases because small, rare patches disappear. The second component, extent, has been defined as "the overall area encompassed by a study, what we often think of (imprecisely) as its scale" (Wiens 1989). Extent is also directly related to the heterogeneity of a landscape: as the total area increases, additional patch types are more likely to be included. Together, the selection of grain and extent control the patterns that can be detected and determine the suitability of any comparison between studies (Wiens *et al.* 1987, Schulz & Joyce 1992, Morris 1987).

Scale, then, refers more to the perception of a landscape, either by a researcher or organism, and is defined by both a fixed grain and extent. Recent experiments have attempted to step away from researcher-imposed definitions of scale, and to determine at what scale animals perceive their environment (Pedlar *et al.* 1997, Moen & Gutierrez 1997). These experiments have progressed from theory to controlled experiments in model systems to studying actual systems at several scales. Through the use of GIS, we now have the ability to systematically vary both the grain and extent of habitat patches. We can explore habitat patterns within a hierarchy of scales and select those that appear to represent an organism-centered perspective. This approach will allow ecologists to understand the impact of scale on species' requirements, and how these requirements change across spatial scales (Baker *et al.* 1995, Kotliar & Wiens 1990). Schulz and Joyce (1992) successfully demonstrated such an approach with simulated landscapes based on a marten habitat model, while Baker *et al.* (1995) applied it to an analysis of nesting sandhill crane habitat. "Studies conducted at several scales or in which grain and extent are systematically varied independent of one another will provide a better resolution of [scale] domains, of patterns and their determinants, and of the interrelationships among scales" (Wiens 1989).

Specifically, the objective of this project was to identify the scale at which adult breeding bald eagles exhibit the greatest non-random response to selected habitat features within their territory. This involves independently identifying both the grain and the extent at which the eagles show the greatest degree of habitat selection. This information can be used to develop a truly eagle-centered perspective of the HRC, allowing for both the accurate classification of potential habitat and better management of existing breeding pairs.

METHODS

Study Area

Currently, three bald eagle pairs are known to be breeding along the Hudson River. Two nests are located within Hudson River National Estuarine Research Reserve at Stockport Flats and Tivoli Bays. The third is located near Catskill. All three nests are situated in fairly isolated and protected portions of the river and are in close proximity to shallow bays or tidal flats, preferred eagle foraging areas. Each territory includes approximately 4-6 miles of shoreline and encompasses a variety of habitat types including tidal flats and wetlands, emergent marsh, upland forest, and numerous degrees of development. These areas also span a wide range of protection, from protected, inaccessible refuges to high use marinas and industrial areas. Boating activity accounts for the highest degree of disturbance to breeding eagles, although the numerous roads, railroads and developments contribute.

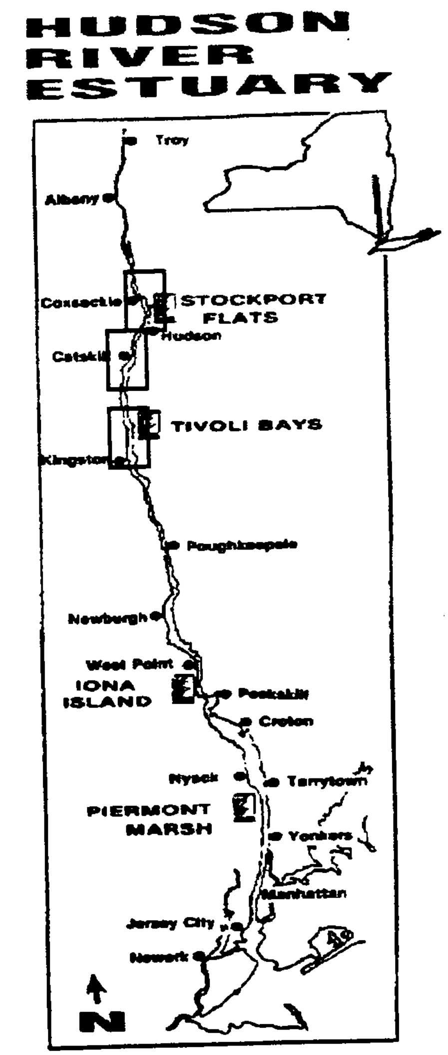


Figure 1. Study area- Hudson River Corridor, NY. Outlined areas are approximate eagle nesting territories.

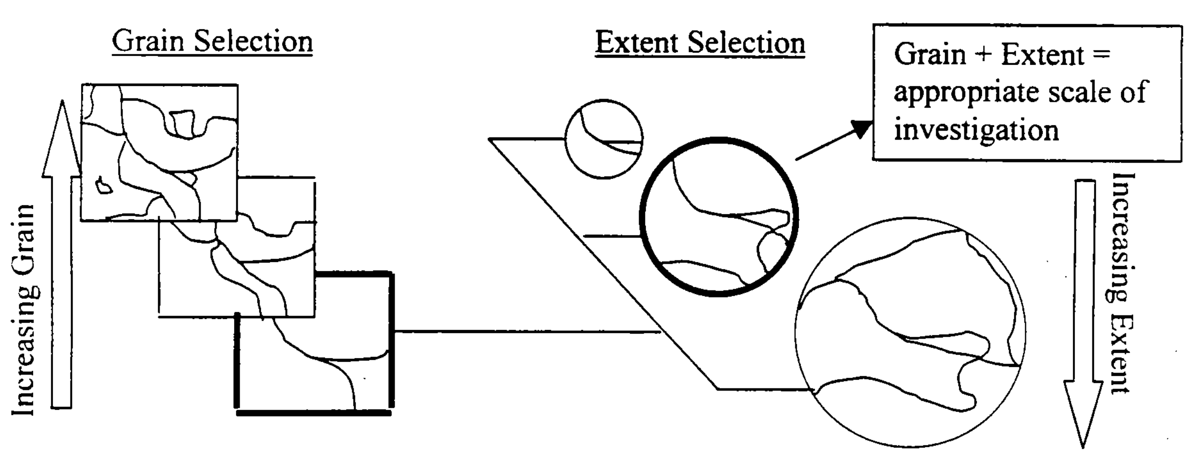
Study design

In order to attempt to identify the scale at which breeding bald eagles perceive their environment, eagle habitat use was quantified at a variety of spatial scales. Scale, defined as a unique combination of grain and extent, was varied systematically and hierarchically for several habitat features known to be important components of quality eagle breeding habitat.

Habitat features were selected to represent important influences on bald eagle behavior and breeding success. Extensive past research has identified three categories of habitat requirements: access to foraging area, nest and perch tree availability, and freedom from human disturbance (Bowerman 1993, Hunt *et. al.* 1992, Hardesty & Collopy 1991, Grubb 1988, Andrew & Mosher 1982, Lukkonnen *et. al.* 1989, Fraser *et. al.* 1985, Anthony & Issacs 1989, Buehler *et. al.* 1991, McEwen & Hirth 1979). Water depth was selected to represent access to foraging areas, based on eagles' traditional use of shallow water as primary foraging areas. Nest and perch tree availability was represented by canopy structure, a combination of seral stage, horizontal canopy closure, and vertical variation. Finally, an index of human activity was created by combining shoreline development data with information concerning temporal human activity (camping, fishing, etc).

For each feature, the scale was systematically varied by varying first the grain, then extent at which the landscape was displayed. Comparison of the degree of eagle habitat selection (use vs. availability) at each grain was used to identify the appropriate grain of investigation. Comparison of landscape patterns using FRAGSTATS software (McGarigal & Marks 1994), allowed for the selection of the appropriate extent of investigation (Figure 2). Together these two values define the scale at which research regarding breeding eagles should be conducted along the HRC. Habitat features were treated independently due to possible differences in how they are perceived by the eagles. To avoid pseudoreplication problems, each pair was considered an independent sampling unit rather than each individual eagle.

Figure 2. Conceptual model of study design- grain and extent variation for the HRC bald eagle population.



Data collection

Eagle habitat use data was collected by conducting intensive, continuous observations (8-10 hours) on each breeding pair once each week throughout the 1999 breeding season. Birds were monitored by boat whenever possible to allow the observer unobstructed views and the ability to follow eagles as they moved throughout their territory. If available through other, concurrent eagle research, telemetry was used to locate and identify each bird prior to an observation and to relocate a bird when visual contact was lost. Eagles' territoriality and tendency to repeatedly use prominent shoreline perches facilitated visual monitoring. Habitat use information was only recorded for visual locations, due to the error associated with telemetry triangulation.

Eagle perch and forage locations were mapped on enlarged copies of 1:12,000 aerial photos. Perch locations were mapped to within a five to ten meter error, while forage locations were mapped to within 20 meters. At each perch location a variety of data was collected, including time of arrival and departure, general behavior, perch tree and adjacent river characteristics, and potential disturbances. For each foraging observation, information concerning the success, prey species, and river characteristics was recorded.

During monitoring periods, information was also collected concerning temporal human activities along the HRC. This included activities such as recreational boating, fishing, camping, and hiking. These activities were recorded throughout observation periods, regardless of proximity to an eagle, in order to quantify the variable nature of potential disturbances within breeding territories. Boats moving in a direct patch along the channel were not recorded due to the high volume and eagles' tendencies to ignore moving objects. These locations were mapped on the same aerial photos as eagle locations, with the same degree of accuracy.

GIS Coverage Development

Digital, 1:12,000 infrared aerial photo images of eagle breeding territories were obtained from TVGA Engineering, Ithaca NY. These images were georeferenced and mosaiced into comprehensive digital maps of each territory using ArcInfo software (ESRI, Redlands CA). GIS point coverages of eagle locations (perch and forage) and temporal human activities were created by visually transferring points between field maps to digital images, both based on the same suite of aerial photographs. GIS coverages of the three critical habitat features, (water depth, canopy structure, human activity), were created through a variety of methods using both ArcView and ArcInfo software (ESRI, Redlands CA).

1) Water Depth

Water depth information was obtained from the NOAA, Special Projects- Estuary Mapping Program. This data was a grid coverage, using a 30-meter cell size at one-meter depth intervals, beginning one meter above mean low water, and covering between Hudson and New York harbor. As this coverage includes only two of the three nesting territories, water depth analysis is limited to these two territories.

Coverages pertaining to each nesting territory were clipped from the larger dataset based on the total range of eagle observations for each pair, defining the available habitat for foraging. Water depth was classed in one-meter increments between one meter above mean low water to four meters depth. Greater than four meters was classed as deep water.

2) Canopy Structure

Canopy structure was represented using a classification scheme based on seral stage, horizontal canopy closure, and vertical variation. Available habitat was defined as a buffer along the shoreline including 95% of all observed perches. A 95% buffer was selected to prioritize shoreline habitat and to remove any excursions outside normal territory boundaries, such as chasing immature eagles from the nesting territory. Canopy structure coverages were digitized from aerial photos (ArcInfo software, ESRI, Redlands CA) using canopy texture (size of individual tree canopies) to approximate seral stage, visual gaps in horizontal canopy, and shadows within the canopy to indicate vertical variation. All areas within the above buffer were classed into one of nine categories:

1) early-seral, no visible variation
2) early-seral, visible variation
3) mid-seral, no visible variation

4) mid-seral, visible variation
5) deciduous late-seral, no visible variation
6) deciduous late-seral, visible variation
7) coniferous late-seral, no visible variation
8) coniferous late-seral, visible variation
9) open

Exact boundaries between canopy types were often hard to define, and the selection of polygon boundaries was subjective. However, forest edge boundaries were drawn with less than a ten-meter error, incorporating individual tree canopies.

3) Human Activity

Human activity coverages were created by combining coverages reflecting shoreline development and temporal human activities. This was done in order to reflect the wide variety of human activities that occur along the HRC.

First, shoreline development was digitized from aerial photos in a method similar to that used for canopy structure. Shoreline development was classified into eight categories; each of which was assigned a value based on the presumed level of disturbance it created for perched eagles (Table 1). These boundaries were easily discernable on aerial photos and digitizing accuracy was less than ten meters.

Table 1. Classes of shoreline development along the Hudson River, New York and the related eagle disturbance weighting value.

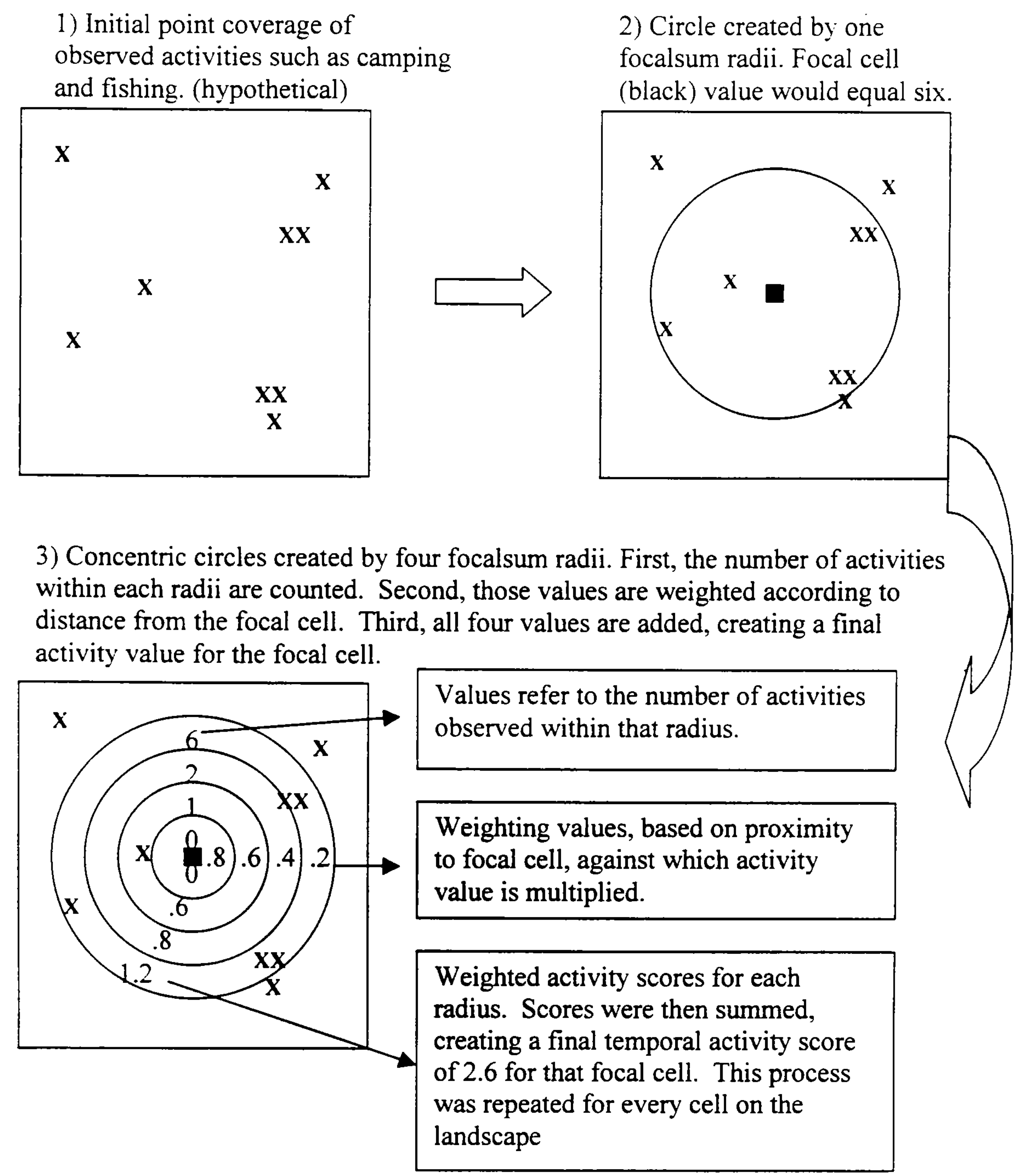
1) Industrial- factories and industrial centers, primarily cement plants	0.6
2) Commercial- town centers and business districts	0.8
3) Residential- housing development, often sparse and well spaced	0.4
4) Marina- high use area with boat access	1.0
5) Road	0.4
6) Railroad	0.2
7) Agriculture- fields and pastures	0.2
8) Undeveloped- either open or forested, no visible development	0.0

Temporal activity coverages began with point coverages of all human activities observed during field data collection that were not associated with some type of fixed shoreline development. This included activities such as fishing, boating, and camping. However, the level of disturbance created by these activities is not limited to the individual point of occurrence, instead extending outward from the original activity but decreasing in intensity with distance. For example, someone hiking along the shoreline may be extremely disturbing to a perched eagle at 20 meters, mildly disturbing at 150 meters, and completely ignored at 400 meters.

In order to approximate this type of disturbance a fine resolution grid was created in which the cell values represented the number of activities surrounding that cell, weighted by distance. This was a fairly complicated procedure and required several steps, primarily done using ArcInfo software. First, a grid with 10-meter cell size was created from the original point coverage, with the cell value representing the number of activities observed at that point. Second, using the ArcInfo 'focalsum' command, cells were assigned new values based on the total sum of all cell values within a defined radius (Figure 3, part 2). For example, a cell was assigned a value of six if six activities were located within that defined radius, and the process was repeated for every cell in the grid. In order to vary the intensity of disturbance based on distance, this process was repeated at 100-meter intervals, resulting four grids based on 100, 200, 300 and 400-meter radii (Figure 3, part 3). A maximum radius of 400 meters was selected based on previous research suggesting 400 meters as the threshold beyond which eagles do not respond to human disturbance (McGarigal *et al.* 1991, Stalmaster & Kaiser 1998).

In each of the four grids created, cell values were multiplied by a weighting factor to emphasize proximity of human activities. Grids of 100, 200, 300, and 400-meter radii were weighted by 0.8, 0.6, 0.4, and 0.2 respectively (Figure 3, part 3). The final step was the merging of the four grids into one, where cell values equaled the sum of the weighted values from each of the four component grids. The final product was a grid of 10-meter cell size, where each cell had a unique value representing the number and proximity of human activities surrounding that point (Figure 3, part 3). High use areas such as campsites or favorite fishing spots were identified by clusters of cells with high activity values.

Figure 3. Outline of the process used to approximate the variable nature of disturbance to eagles created by temporal human activities along the Hudson River, New York.



Before combining the development and temporal activity grids, shoreline development activity scores were weighted by a factor of 20 to account for the constant disturbance they represent. Mathematically, this resulted in a marina having an activity score twice that of a high use camping area, with the high use camping area ranked between residential and industrial areas. Once both grids were combined, the result was a grid, composed of 10-meter cells, representing the total level of human activity within each nesting territory. Final activity scores, the sum of the component scores, ranged between zero and thirty. These were standardized to between zero and one to simplify interpretation.

Data Analysis

1) Grain Analysis

Beginning with the base coverage for each habitat feature, the grain, or resolution was varied over a selected range by steadily increasing the cell size (Brooks 1997), either by converting polygonal coverages to grids at selected cell sizes or resampling grids at new cell sizes. The exact grains selected varied between habitat features based on original data resolution and extent, but represented a range of possible scales (Table 2). This served to vary the grain of investigation in a controlled manner. Any habitat patches not meeting the minimum cell size criteria were absorbed into surrounding patches, thereby reducing the landscape heterogeneity as the grain was increased (Brooks 1997).

At each grain size, habitat selection was quantified using a chi-squared analysis, and Bonferroni's adjustment was used to account for potential errors involved in making multiple comparisons (Neu *et al.* 1974, Litvaitis *et.al.* 1996). Results were considered significant at p=.05. Data was pooled between all nesting territories to increase statistical power, though this resulted in a loss of information concerning individual animal

Table 2. Different grain sizes at which use vs. availability analysis were conducted.

Habitat feature	Original resolution	Selected grains (cell size)				
Water Depth	30 meter	___	30m	75m	150m	250m
Canopy Structure	10 – 15m	10m	30m	75m	150m	___
Human Activity	10m	10m	30m	75m	150m	400m

selection. The absolute magnitude of the chi-squared statistic was used to compare the degree of selection between grains, and confidence intervals were calculated for each habitat category within each grain to document specific selection or avoidance.

2) Extent Analysis

The impact of extent was quantified by examining the landscape patterns surrounding each perch or forage location and comparing this to landscapes surrounding randomly selected points within each territory. By varying the amount of landscape taken into consideration, the extent could be varied in a controlled manner. This was accomplished through the gradual increase in diameter of a window placed around each point.

Before beginning the analysis, two variables had to be selected. First, the extents to be considered were selected based on the grain identified in the preceeding analysis. Extent ranges were started at or below the selected grain then increased at discrete intervals (Table 3). Second, landscape metrics were selected to quantify landscape pattern around each point and to use for comparison both between used and random sites, and between different extent values. The primary consideration in metric selection was that metrics were insensitive to the total amount of landscape area, as increasing extent by definition increases the total area considered, and secondarily to represent a range of the components of landscape pattern. This resulted in the selection of five metrics that were weighted by area:

<u>Selected metrics</u>

1) Edge density (ED)- sum of all patch edge lengths / total landscape area, represents the number and shape of patches.
2) Largest patch index (LPI)- area of largest patch / total landscape area. Represents how much the landscape is dominated by one patch.
3) Area-weighted mean patch fractal dimension (APF)- represents the irregularity of patch shapes.
4) Patch density (PD)- total number of patches / total landscape area, represents the number and size of patches.
5) Percentage of landscape (%LAND)- the total percent of landscape for each patch type, represents landscape dominance by a particular patch type.

Table 3. Different extent values at which landscape analysis of used vs. random landscapes was conducted.

Habitat feature	Selected extents				
Water Depth	____	75m	150m	300m	450m
Canopy Structure	50m	100m	200m	400m	600m
Human Activity	____	400m	600m	800m	1000m

To select the random points against which used landscapes could be compared, a fine resolution grid (5 meter cells) was overlaid on each of the GIS coverages. This grid was then clipped to match the available habitat coverage, and cells within the grid were randomly selected using the ArcGrid RAND feature, until the number equaled the number of perch or forage locations for that territory.

Around each point, both used and random, perch and forage locations, buffers were created corresponding to a particular extent value. Overlapping portions of these buffers were dissolved to create discrete polygons. These polygon coverages were then used to clip the actual entire landscape coverages, mapped at the grain selected in the previous analysis, with the result being a grid coverage of the portion of the landscape falling within a specified distance of a point for each of the three habitat features. FRAGSTATS was then used to calculate the selected metrics for each clipped landscape. Finally, comparisons were made between used and random landscapes using a simple ratio of metric values, which showed the degree of change between metrics for each habitat feature and extent value.

RESULTS

Data Collection

Between 26 March and 15 July 1999, a total of 137.5 hours were spent observing habitat use by breeding eagles, and resulted in the recording of 255 perch locations and

Table 4. Results of field data collection of bald eagle habitat use along the Hudson Corridor, New York.

Breeding Pair	Observation time	Perch sites observed	Forage locations observed
TB	51 hours, 7 min.	103	16
IB	49 hours, 8 min.	88	17
SF	37 hours. 15 min.	64	12

45 forage locations. Per nest, total results varied based on the difficulty of maintaining visual contact with moving eagles (Table 4).

Grain Analysis

For each of the three habitat features, the grain at which the eagles showed the highest degree of selection, based on the chi-squared statistic, was selected. This resulted in clear selections in two of the three cases. In the third case, interpretation of both the change in the chi-squared statistic and the confidence limits of each category was required to determine the grain of selection.

1) Human Activity

Between 10 and 150-meter grain sizes, eagles showed a low level of selection for areas with low but not nonexistent, human activity. However at the 400-meter cell size, the chi-squared value jumped from an average of approximately 23 to 58, showing a drastic increase in selection (Figure 4). This degree of selection was driven by a significant avoidance of areas with a human activity value between 0 and .1, and strong selection for areas with activity values between .1 and .2.

2) Canopy Structure

Eagles showed a high level of selection for late seral stands with variable structure, both deciduous and coniferous at all scales. However, this selection dropped between 75 and 150-meter grains (Figure 5), suggesting some shift in selection at that point. This selection was also associated with an avoidance of younger stands and open areas.

Figure 4. Bald eagle habitat selection based on human activity at selected grain sizes along the Hudson River, New York. Cell sizes are in meters squared.

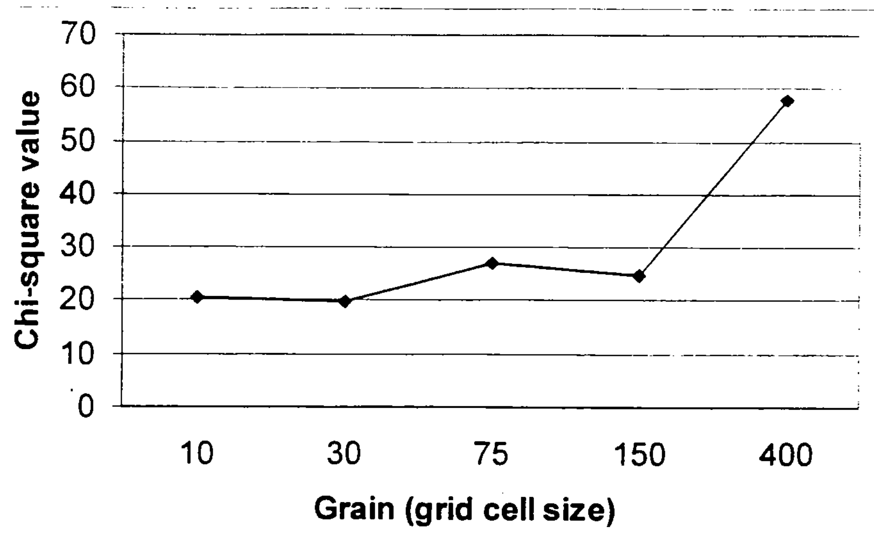
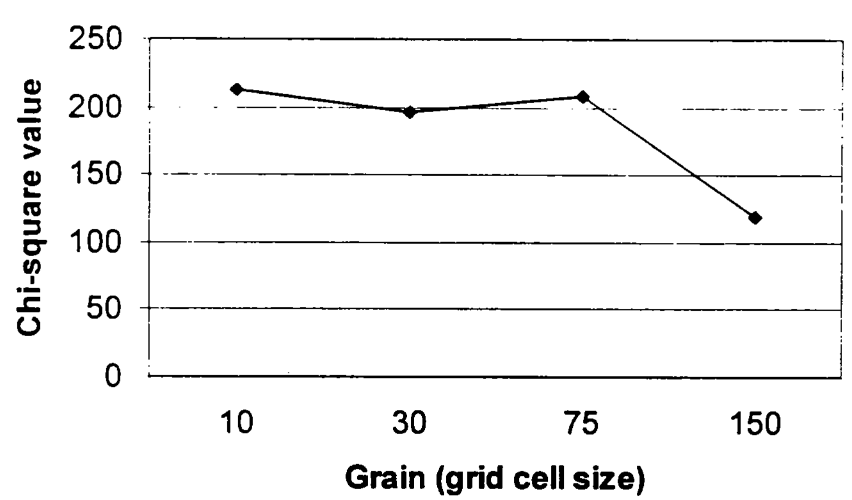


Figure 5. Bald eagle habitat selection based on canopy structure at selected grain sizes along the Hudson River, New York. Cell sizes are in meters squared.

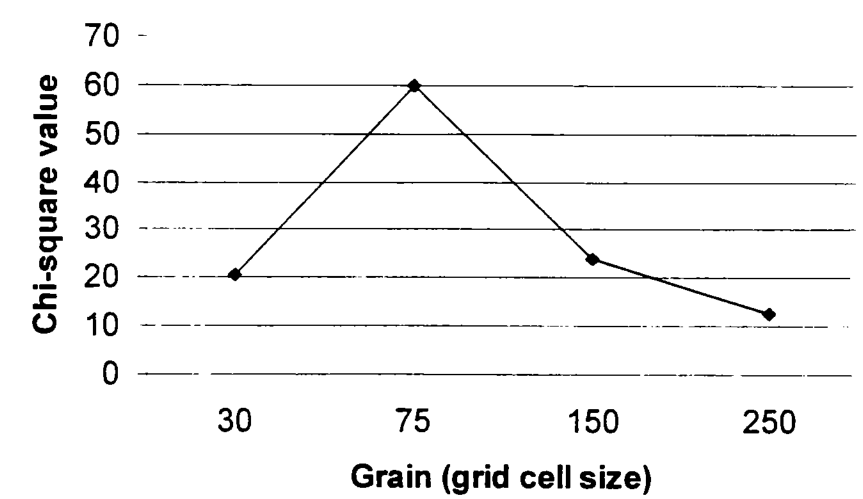


3) Water Depth

At both low and high grains, eagles showed a low degree of selection, primarily reflecting an avoidance of deeper (> 4 meter) water, with chi-square values ranging between 12.58 (non-significant) and 24.09. At the 75 meter grain, the chi-square value

jumped to 60.05 showing a strong increase in selection for areas between 0 and 1 meter above mean low water (tidal flats) (Figure 6).

Figure 6. Bald eagle habitat selection based on water depth at selected grain sizes along the Hudson River, New York. Cell sizes are in meters squared.



Extent Analysis

At each extent, the difference between used and random metric values was compared to evaluate habitat selection. The degree of change was then compared between extents to establish the extent at which the eagles again showed the highest degree of selection. Two of the five metrics, largest patch index and percentage of landscape, showed some degree of variation at both comparisons. The other three showed no real change. The patterns of selection observed mimicked that seen in the grain analysis, with two of the features, canopy structure and water depth, showing higher degrees of selection.

1) Human activity

No real pattern was apparent between either the used and random landscape metrics or landscape metrics for different extents (Table 5).

Table 5. Landscape metric values associated with both actual and random landscapes along the Hudson River, New York, at varying extent values. Ratios represent the difference between used and available habitat at each extent. Ratios that are significantly different that 1.0 are identified by boldface type.

Human activity

Extent	LPI	PD	ED	APF
400	18	2.13	11.25	1.04
rnd400	27.92	1.74	12.56	1.08
ratio	0.645	1.22	0.896	0.96
600	20.86	1.84	13.67	1.06
rnd600	29.05	1.58	14.63	1.07
ratio	0.718	1.165	0.934	0.991
800	31.11	1.53	13.33	1.07
rnd800	28.63	1.59	15.73	1.07
ratio	1.087	0.96	0.847	1.0
1000	32.52	1.61	14.08	1.06
rnd1000	28.51	1.61	15.86	1.07
ratio	1.141	1.0	0.888	0.991

Canopy structure

Extent	**LPI**	PD	ED	APF
50	**6.06**	129.3	29.63	1.03
rnd50	**2.01**	127.2	28.09	1.02
ratio	**3.015**	1.016	1.055	1.01
100	**11.67**	60.44	49.33	1.07
rnd600	**2.41**	72.24	61.77	1.04
ratio	**4.842**	0.837	0.799	1.03
200	**27.33**	37.98	60.08	1.09
rnd200	**3.85**	46.36	72.06	1.07
ratio	**7.099**	0.819	0.834	1.02
400	23.18	29.34	60.05	1.09
rnd400	18.64	34.86	66.35	1.09
ratio	1.224	0.842	0.905	1.0
600	20.34	31.25	61.41	1.09
rnd600	19.48	33.68	65.87	1.0
ratio	1.044	0.928	0.932	1.0

Water depth

Extent	**LPI**	PD	ED	APF
75	**9.8**	83.66	26.14	1.03
rnd75	**3.85**	95.73	28.21	1.01
ratio	**2.545**	0.874	0.927	1.02
150	**17.44**	25.53	42.39	1.06
rnd150	**3.88**	37.97	53.72	1.04
ratio	**4.495**	0.672	0.789	1.02
300	**18.06**	14.87	42.59	1.08
rnd300	**6.23**	22.9	58.54	1.05
ratio	**2.899**	0.649	0.728	1.03
450	**16.48**	14.19	48.04	1.08
rnd450	**5.1**	19.47	60.79	1.07
ratio	**3.231**	0.729	0.79	1.01

rnd- designates random landscapes

LPI = largest patch index
PD = patch density
ED = edge density
APF = area weighted mean patch fractal dimension

2) Canopy structure

At smaller extents, eagles used a slightly greater percentage of both coniferous forest and open land than was available. These percentages equalized as the extent was increased, with no apparent peak (Table 6). However, used habitat showed a much greater largest patch index at a 200-meter extent than randomly selected habitat (Table 5). This value was primarily driven by large patches of open area in used habitat, including areas of marsh or tidal flat. On average, used habitat contained open patches that were 7.1 times larger than those patches found in random habitat.

3) Water depth

Across all extents, eagles showed a greater use of water between one meter above and one meter below mean water depth (depth class one) than other depth classes (Table 7). This selection peaked at the 150-meter extent, with used habitat containing 3.6 times more shallow water than random areas. Also at 150-meter extent, the largest shallow water patch index was 4.5 times larger in used habitat than in random habitat (Table 5).

Table 6. Ratios of used vs. available habitat based on canopy structure and total landscape percentage recorded at variable extent values. Ratios are the average of multiple canopy structure categories within that landscape type.

Extent	Landscape type, ratio of used vs. available habitat		
	Late seral conifer	Open land	Other
50	1.419	1.639	.491
100	1.482	1.556	.597
200	1.308	1.313	1.049
400	1.284	1.074	1.169
600	1.276	1.061	1.068

Table 7. Ratios of used vs. available habitat based on water depth and total landscape percentage recorded at variable extent values.

	75m extent	150m extent	300m extent	450m extent
Depth class 1	3.398	3.657	2.869	2.041
Depth classes 2-9 (mean)	.313	.403	.509	.664

DISCUSSION

Human Activity

At the 400-meter grain, eagles showed a dramatic increase in habitat selection. This coincides with past research (McGarigal *et al.* 1991) that recommended a management buffer zone of 400 meters around eagle foraging areas based on eagle reactions to human disturbance on the Columbia River, Oregon. Intuitively, this also makes sense based on eagles' tendency to avoid areas of high human activity.

More interesting is the fact that at the 400-meter extent, eagles showed significant selection against areas of no human activity, and selection for areas with low activity scores (between .1 and .2). This may suggest the use of the same fishing 'hot spots' by both eagles and anglers. While eagles are rarely seen in these areas while fishermen are present, they may be using these areas during times of low fishermen activity, such as dawn and dusk. This would suggest some type of temporal discrimination in habitat use, rather than a direct spatial selection or avoidance.

No apparent selection was observed at any of the four extents investigated. This is primarily due to the large grain at which eagles show selection. Above a 400-meter extent, random and used landscapes begin to overlap to a degree that makes comparison difficult. One possible approach to this problem would be to consider each landscape polygon individually rather than merging polygons into general used vs. random habitats. This would allow for the use of multivariate, discriminate analysis of landscape metrics, which may be more effective.

Canopy Structure

No obvious peak at a particular grain appeared in eagle selection of habitat based on canopy structure, as was seen in both the water depth and human activity data. Instead, selection remained high at several small grains, then dropped after a 75-meter grain. Wiens (1989) suggested the existence of 'domains of scale', a range of scales over which similar levels of selection were observed rather than a particular peak. Each domain may represent a range of scales within which organisms did not discriminate on the basis of scale, but the range is bounded by scales of selection or avoidance. The observed pattern in eagle selection of canopy structure appears to follow Wiens' hypothesis rather than display distinct selection. From a management perspective, this may reflect an eagle's ability to find suitable perches within the majority of forest stands, but preference for older, open stands.

At smaller extents, eagles showed preference for landscapes with greater percentages of open landscape. This trend was most apparent at a 200-meter extent, where the largest open patch in used habitat was just over seven times larger than patches found in random landscapes. This probably reflects eagles' tendency to perch along forest edges, where they are provided the widest view (Stalmaster 1987). Additionally, this was heavily influenced by several large marshes and tidal flats, areas where eagles appeared to spend large amounts of time hunting.

Water Depth

Of all three habitat features, eagles showed the strongest scale-dependent selection with regards to water depth. Of 32 observed forages within the two territories encompassed by the NOAA water depth data, 31 occurred in areas between one meter above and one meter below mean low water. This selection was the strongest at a 75-meter cell coupled with a 150-meter extent, indicating that eagles select large foraging areas based on fairly general characteristics. At a 75-meter grain, most of the fine-scale variations in depth is obscured. Instead, eagles appear to select foraging areas based on the existence of fairly large areas of generally shallow water. On average, landscapes used for foraging contained 3.6 times more shallow water that random landscapes.

All three nesting territories contained two large areas of shallow water in the form of bays, eddies or tidal flats, that were heavily utilized by eagles as foraging areas. Such areas are not overly common along the Hudson River. Therefore the existence of two such areas in close proximity may be an important factor in identifying potential eagle breeding habitat along the HRC.

RECOMMENDATIONS

For all three habitat features, eagles showed some degree of scale-dependent selection. Most likely, in all three cases selection is highest over some range, or domain, of scale as proposed by Wiens (1989). The scales identified in this study indicate where to look for these domains, but the actual boundary scales and domain width are yet undetermined. These boundaries may play an important role in the evaluation of eagle breeding habitat, in that landscapes viewed at scales outside the proper domain may be irrelevant from an eagle's perspective. Future research needs to both increase the sample size and related statistical strength, and to increase the range and resolution of scales investigated. This may be as simple as evaluating grains over a larger range, and increased by some small, regular interval.

Very few wildlife studies that we are aware of have attempted to quantify the variable impact of temporal human activity. However, this makes intuitive sense as one of the primary factors in an eagle flushing is the distance to the disturbance (McGarigal *et al.* 1991, Grubb 1976, Buehler *et al.* 1991). Further research and larger sample sizes are required to validate our approach. Also, it may be suspected that shoreline development, traditionally viewed as fixed, exhibits a similar form of radiating influence and should be treated in a similar manner. In addition, some attempt should be made to separate spatial and temporal scales of human disturbance. Eagles' selection of large areas of low human activity suggests the potential for conflict over shared resources, and future research should address this concern.

Finally, the most important potential use of this information is in the identification of other potentially viable nesting habitats within the HRC. Once resources are displayed at the proper scale, existing territories can be used as prototypes with which to compare other, currently unoccupied areas. Areas that are similar to existing nesting territories in

both composition and configuration can then be both monitored and protected while the population naturally expands.

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