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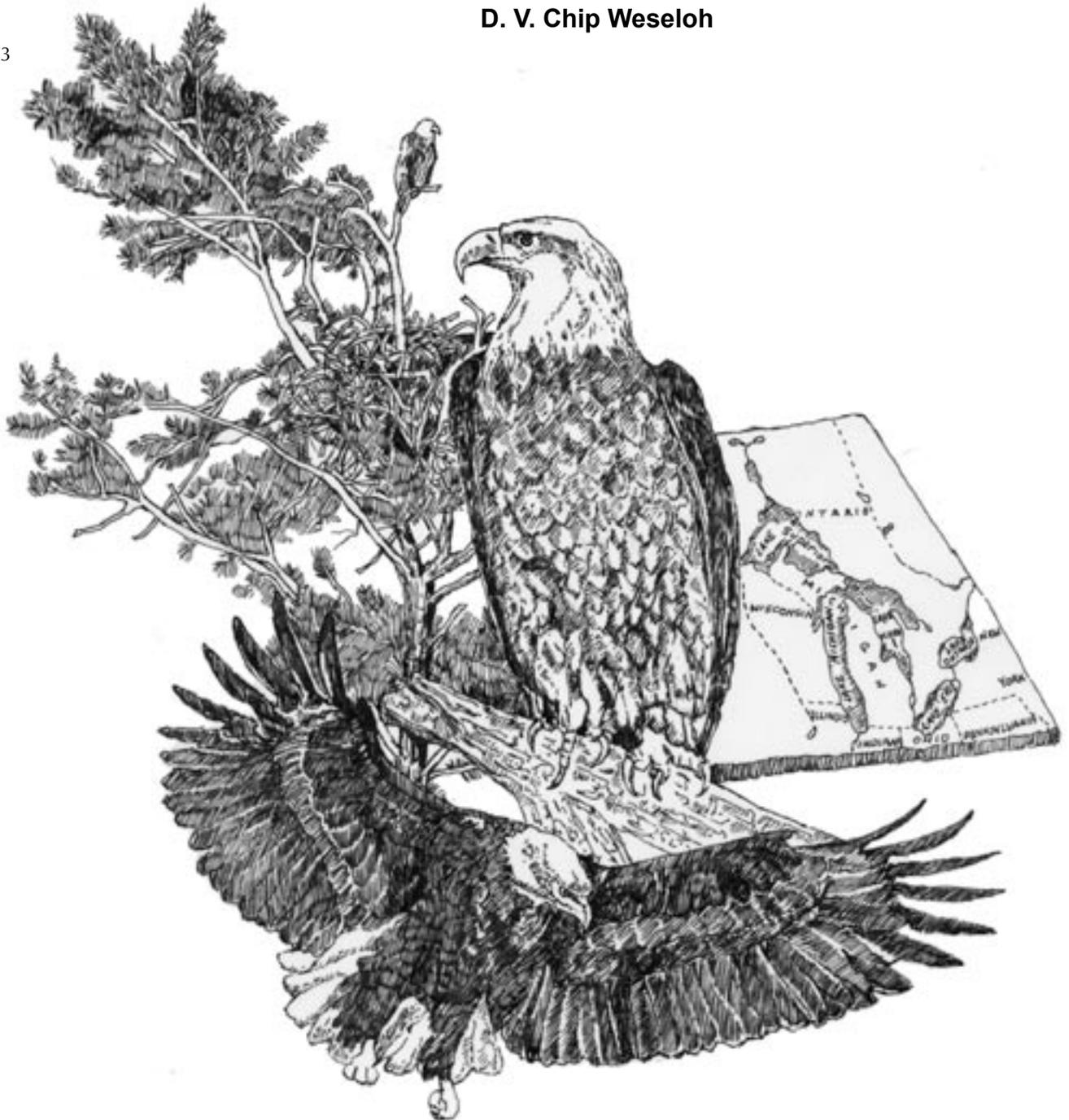
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# Evaluating Great Lakes Bald Eagle Nesting Habitat With Bayesian Inference

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## Abstract

Bayesian inference facilitated structured interpretation of a nonreplicated, experience-based survey of potential nesting habitat for bald eagles (*Haliaeetus leucocephalus*) along the five Great Lakes shorelines. We developed a pattern recognition (PATREC) model of our aerial search image with six habitat attributes: (a) tree cover, (b) proximity and (c) type/amount of human disturbance, (d) potential foraging habitat/shoreline irregularity, and suitable trees for (e) perching and (f) nesting. Tree cover greater than 10 percent, human disturbance more than 0.8 km away, a ratio of total to linear shoreline distance greater than 2.0, and suitable perch and nest trees were prerequisite for good eagle habitat (having sufficient physical attributes for bald eagle nesting). The estimated probability of good habitat was high (96 percent) when all attributes were optimal, and nonexistent (0 percent) when none of the model attributes were present. Of the 117 active bald eagle nests along the Great Lakes shorelines in 1992, 82 percent were in habitat classified as good. While our PATREC model provides a method for consistent interpretation of subjective surveyor experience, it also facilitates future management of bald eagle nesting habitat along Great Lakes shorelines by providing insight into the number, type, and relative importance of key habitat attributes. This practical application of Bayesian inference demonstrates the technique's advantages for effectively incorporating available expertise, detailing model development processes, enabling exploratory simulations, and facilitating long-term ecosystem monitoring.

**Keywords:** aerial surveys, bald eagle, Bayesian inference, Great Lakes, habitat modeling, *Haliaeetus leucocephalus*, nesting habitat, pattern recognition.

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Bayesian inference has been used effectively in both ecological research and environmental decisionmaking (Ludwig 1996; Taylor and others 1996; Ver Hoef 1996; Wolfson and others 1996). However, there is still controversy (Dixon and Ellison 1996) between the traditional frequentist point of view (Dennis 1996) and proponents of Bayesian statistics—not over Bayes' theorem but over its use and derivative applications. One benefit of Bayesian methods, appealing to the ecologist not conversant in statistical theory, is a mathematical formalization of intuitive interpretation of data in light of preexisting information (Edwards 1996). Bayesian inference can provide meaningful interpretation for a nonreplicated study (Reckhow 1990) and is often more compatible with scientific needs and judgment than classical hypothesis testing (Wade 2000).

Pattern recognition (PATREC) (Kling 1980; Williams and others 1977) is an elementary but practical application of Bayes' theorem, which provides an explicit framework for incorporating prior knowledge into an analysis. PATREC estimates the probability of good habitat given the inventory data ( $P(G/ID)$ ) from the probability of the inventory data given good habitat ( $P(ID/G)$ ). This Bayesian approach is appropriate for classification of nesting habitat, for example, because Bayesian analyses estimate probability distributions that can be used directly in habitat suitability decisions (Taylor and others 1996) and are easily interpreted for more target-specific resource management (Ellison 1996).

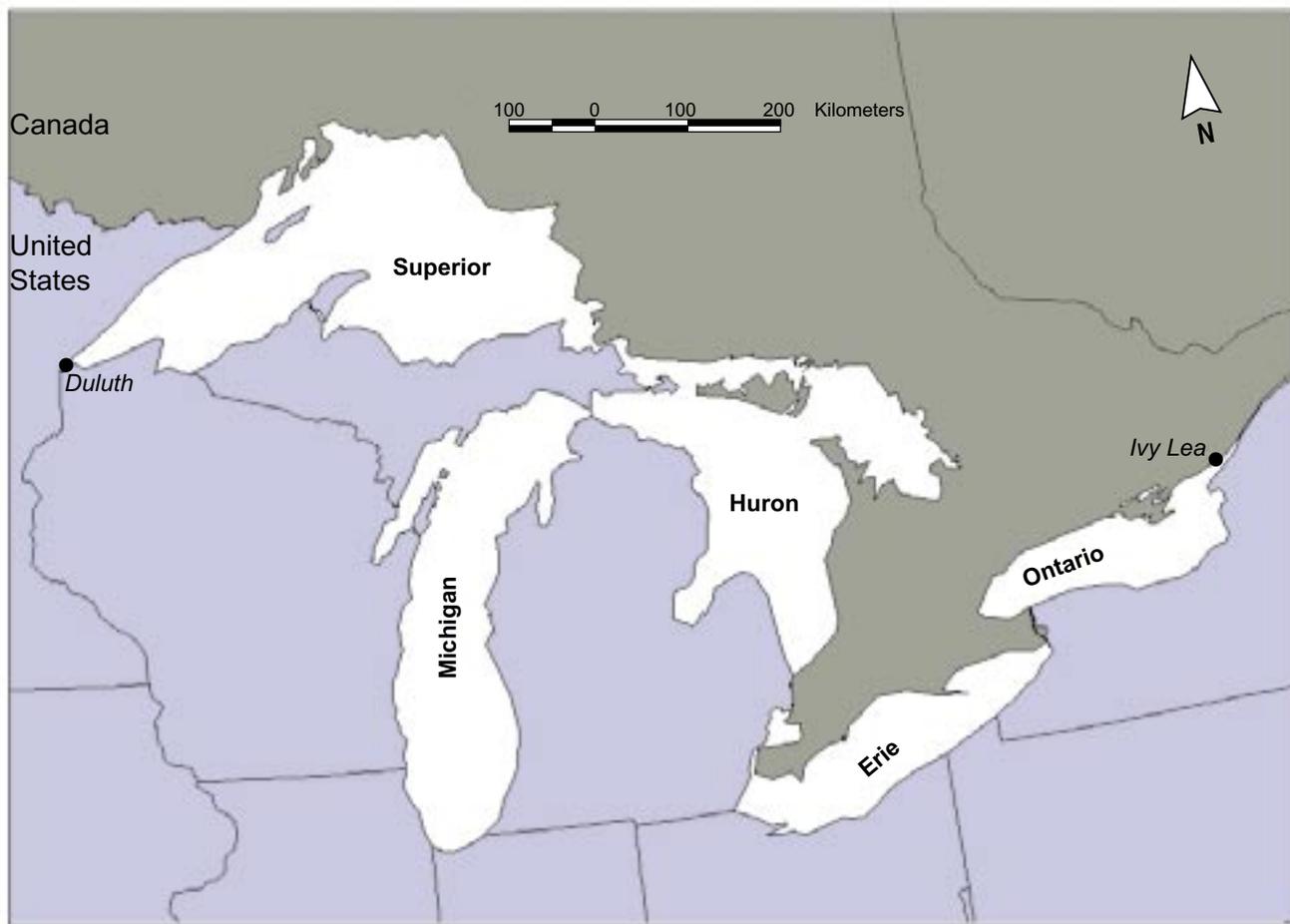
From a comprehensive aerial survey of the five Great Lakes shorelines during 1992 (Bowerman and others, in press), we identified potential bald eagle (*Haliaeetus leucocephalus*) nesting habitat as part of a proposed ecosystem monitoring program for the Great Lakes (Bowerman and others 1993; International Joint Commission 1989). Our primary goal in developing a Bayesian model of the search pattern used in conducting this aerial habitat survey was to capture the authors' expertise and communicate it in a way that less familiar biologists could use the resultant model to facilitate

subsequent nesting habitat inventory, evaluation, and management. PATREC provided the means of organizing our collective experience sufficiently to develop such a probabilistic model.

Our secondary purpose was to demonstrate several advantages of Bayesian inference in habitat evaluation, including: (a) incorporating prior experience into a simple habitat model that can be applied effectively by less familiar biologists; (b) defining specific habitat attributes, differentiating characteristics, and threshold levels among habitat suitability classes during model development; (c) enabling exploratory simulations to evaluate the relative importance of specific habitat attributes or habitat management actions under varying conditions; and (d) providing a baseline framework for assessing habitat to facilitate long-term ecosystem monitoring.

## Study Area

The study area included habitat within 1.6 km of the United States and Canadian shorelines of the five Great Lakes, including all islands and connecting channels, bounded on the west by the Harbor of Duluth/Superior at the western end of Lake Superior and on the east by the International Bridge spanning the St. Lawrence River at Ivy Lea, Ontario, Canada (fig. 1). Generally, shoreline irregularity and island frequency decreased while coastal development increased, moving south and east from Lake Superior to Lake Ontario. Vegetative cover also varied across the Great Lakes Basin. Northern spruce-fir forest occurred along the north shore of Lake Superior. Major tree species were aspen (*Populus grandidentata*, *P. tremuloides*), spruce (*Picea mariana*, *P. glauca*), and balsam fir (*Abies balsamea*). Mixed northern hardwood-pine forest occurred in the central lakes area along the south shore of Lake Superior and northern shores of Lakes Michigan and Huron. Dominant species were maple (*Acer rubrum*, *A. saccharum*), oak (*Quercus rubra*,



**Figure 1**—The five Great Lakes, whose shorelines, islands, and connecting channels between Duluth, MN, and Ivy Lea, Ontario, were included in an aerial survey of potential bald eagle nesting habitat in 1992.

*Q. alba*), and pine (*Pinus strobus*, *P. banksiana*, *P. resinosa*). Mainly oak forests (*Quercus* spp.) occurred along southern Lakes Michigan and Huron, Lake Erie, and western Lake Ontario. Mixed forest with species similar to the central lakes occurred along eastern Lake Ontario (Great Lakes Basin Commission 1975).

## Methods

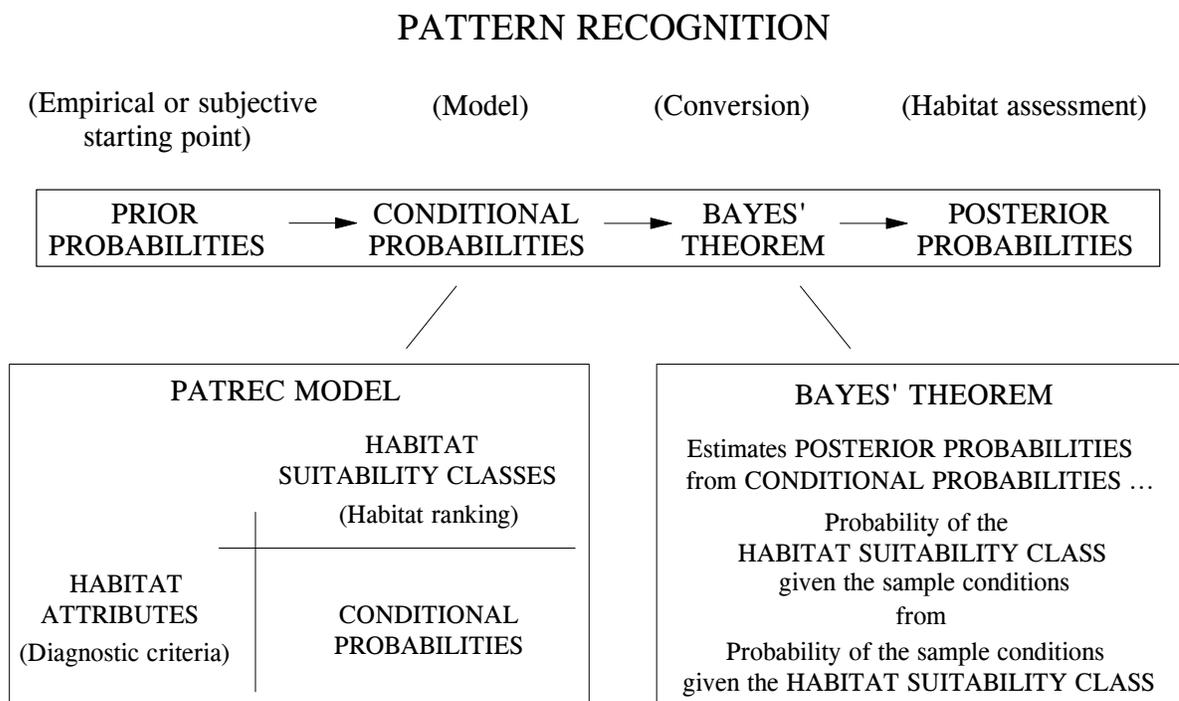
Table 1 summarizes our procedures for developing a PATREC model. PATREC is a simple Bayesian model (Edwards and others 1963) that estimates the probability of a particular habitat suitability class given a set of sample habitat conditions (fig. 2; Grubb 1988). Input for the model consists of two types of probabilities or frequencies of occurrence: (a) prior (expected) probability of each habitat suitability class across the entire survey area, and (b) conditional probability of each habitat attribute given the presence of each habitat suitability class. As stated by Kling (1980):

Frequencies of occurrence for the various habitat suitability classes can be called conditional probabilities and habitat attributes can be called diagnostic criteria. Diagnostic criteria and their associated conditional probabilities are used to evaluate an area of unknown quality by ascertaining the status (presence or absence) of the habitat attributes and then calculating the probability of the area being highly suitable with the use of Bayes' theorem and conditional probability values.

Our aerial survey search image consisted of habitat attributes we considered critical to bald eagle nesting based on our collective experience. We defined good habitat as having sufficient physical attributes for the presence of bald eagle nesting. Marginal habitat lacked in one or more types and/or extent of the physical attributes associated with good habitat. Unsuitable habitat had insufficient physical attributes to support typical bald eagle nesting.

**Table 1**—Procedures used in developing a Bayesian pattern recognition (PATREC) model for inventorying, evaluating, and managing Great Lakes bald eagle nesting habitat.

- Step 1. *Search Image* - Based on more than 60 years' prior experience with bald eagles throughout much of their range, we had an established search image for evaluating potential shoreline nesting habitat; otherwise we would have developed one from available expertise, literature, or empirical data.
- Step 2. *Aerial Survey* - We conducted a comprehensive aerial shoreline survey of potential bald eagle nesting habitat within 1.6 km of the United States and Canadian shorelines of the five Great Lakes (Bowerman and others, in press).
- Step 3. *Habitat Classification* - During the aerial survey, we classified shoreline habitat as good, marginal, or unsuitable for bald eagle nesting (table 2).
- Step 4. *Model Building* - Following our survey, we developed a PATREC model of our search image (fig. 2; table 3) with:
- (a) *Prior Experience* - by using our prior experience (step 1) to identify habitat attributes and the conditional probability of each habitat attribute given the presence of each habitat suitability class (for example, probability of additional potential foraging habitat being present was 0.60 in our overall experience).
  - (b) *Probability Tuning* - by adjusting conditional probabilities (step 4a) to yield results consistent with our experienced-based aerial search image and to enhance overall accuracy of the final model (example continued, survey effort suggested greater importance of potential foraging habitat along Great Lakes shoreline, estimated conditional probability increased to 0.75).
  - (c) *Survey Data* - (i) by measuring the amount of shoreline surveyed into each habitat suitability class (steps 2 and 3) for determining prior probabilities of habitat classes (table 2), and (ii) by using survey data to estimate the probability of each habitat attribute given the observed presence of each habitat suitability class for adjusting the conditional probabilities of Step 4a to the Great Lakes shoreline (example continued, from survey data, potential foraging habitat occurred in 90 percent of sites classified as good; therefore conditional probability adjusted to 0.90).
- Step 5. *Model Assessment* - We assessed the accuracy of our habitat classification (step 3) and resultant PATREC model (step 4c; table 3) by comparing locations of active bald eagle nests in 1992 with our predicted habitat quality.
- Step 6. *Exploratory Simulation* - Finally, we used our PATREC model (table 3) to evaluate the influence of each identified habitat attribute on habitat suitability under varying hypothetical habitat conditions (tables 4 and 5).



**Figure 2**—Schematic of the pattern recognition (PATREC) habitat modeling process (reprinted from Grubb 1988, with permission). The lower left box shows the actual model. The lower right box displays the Bayesian estimation of posterior probabilities from conditional probabilities, or the final habitat assessment. Prior probabilities are a best estimate of the probability of occurrence for each of the habitat suitability classes.

PATREC uses prior and conditional probabilities to estimate the posterior probability for each habitat suitability class via the following equation (Grubb 1988; Williams and others 1977):

$$P(G/ID) = \frac{P(G) P(ID/G)}{P(G) P(ID/G) + P(M) P(ID/M) + P(U) P(ID/U)}$$

where

$P(G/ID)$  = posterior probability of good habitat given the inventory data,

$P(G)$  = prior probability of good habitat,

$P(ID/G)$  = probability of inventory data given good habitat, that is, the product of all conditional probabilities in this suitability class (if an attribute is not present, then the conditional probability for that attribute is subtracted from 1.00 before being multiplied),

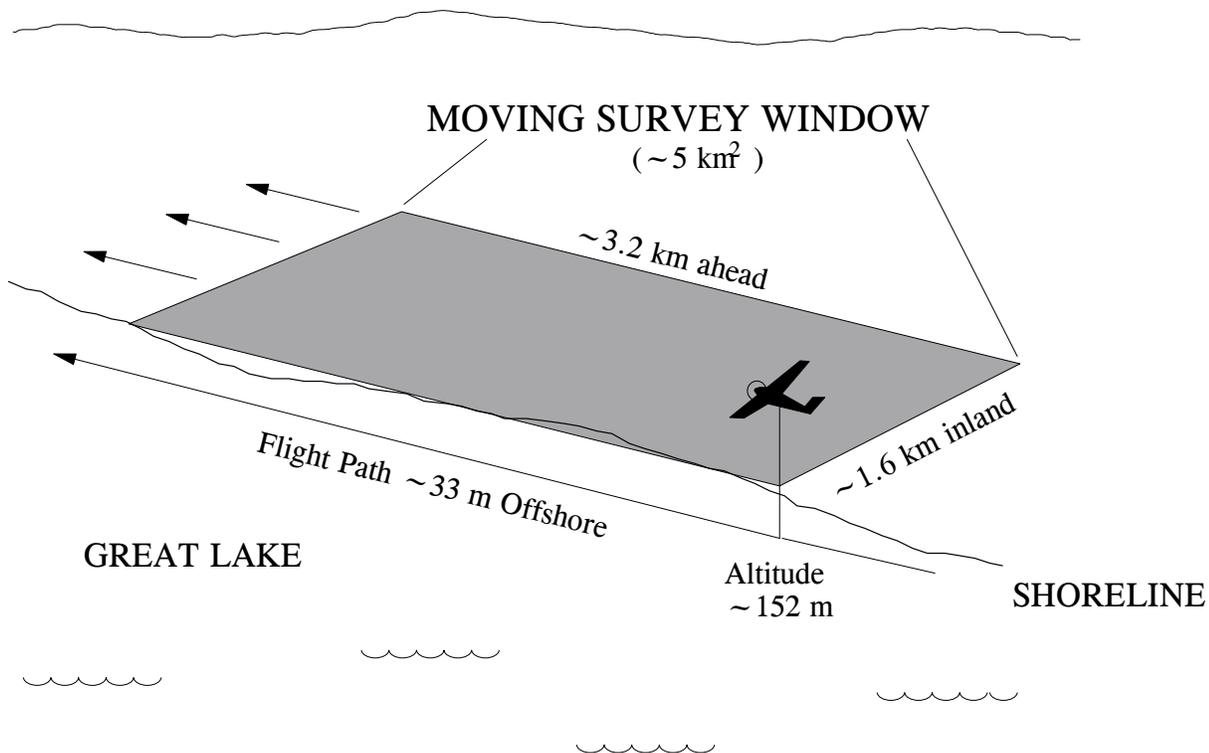
M = marginal habitat,

U = unsuitable habitat.

( $P(M/ID)$  and  $P(U/ID)$  are calculated by substituting appropriate values of M and U, respectively, for G in the numerator.)

We developed our model by delineating and refining independent habitat attributes evaluated during our aerial survey (tree cover, human disturbance, foraging habitat/shoreline irregularity, trees for perching and nesting). Our area of consideration was an approximately 5-km<sup>2</sup> moving survey window, which is the typical area visible to a single observer in a fixed-wing survey aircraft flown along a shoreline (fig. 3). We estimated prior probabilities by planimetrically determining amount of surveyed shoreline in each habitat suitability class for each Great Lake, calculating class totals, and determining the relative percentages of each class (table 2). Because the first two attributes in our model (tree cover and disturbance proximity) eliminated approximately 90 percent of the unsuitable habitat, we based prior probabilities in our model on the remaining habitat. For example, municipal and treeless shorelines were not included in prior probability calculation.

We developed conditional probabilities by estimating the probability of each habitat attribute given observed presence of each habitat suitability class during the aerial survey, and by making similar frequency-based estimates from our more than 60 years' collective experience with bald eagle nesting habitat in some 21 States and four Provinces since 1967. During this second pro-



(Not drawn to scale)

**Figure 3**—The approximately 5-km<sup>2</sup> moving survey window used to evaluate bald eagle nesting habitat along the Great Lakes shorelines in 1992, and the area of consideration for a subsequently derived PATREC habitat model.

**Table 2**—Amount of shoreline surveyed in each habitat suitability class for each Great Lake during a 1992 aerial survey for potential bald eagle nesting habitat (Bowerman and others, in press), and the derivative calculation of prior probabilities for a pattern recognition (PATREC) model of the aerial search image.

	Habitat suitability class			
	Good km (%)	Marginal km (%)	Unsuitable km (%)	Total km (%)
Survey totals	4,991 (47)	2,015 (19)	3,590 (34)	10,596 (100)
Adjusted totals <sup>a</sup>	4,991 (68) <sup>b</sup>	2,015 (27) <sup>b</sup>	359 (5) <sup>a,b</sup>	7,365 (100)

<sup>a</sup> Approximately 90 percent of unsuitable habitat was eliminated because of a lack of tree cover and proximity to human disturbance.

<sup>b</sup> 68 percent good, 27 percent marginal, and 5 percent unsuitable shoreline habitat became the prior probabilities used for developing our PATREC model (table 3).

cess, we tested and refined initial probability estimates by evaluating a variety of hypothetical situations (for example, a suitable nest tree with no available perch trees, or an irregular shoreline with a nearby marina, and so forth) in order to maximize model consistency with our in-the-field, aerial assessment of the same habitat circumstances. This expert elicitation of probabilities was application-specific (Kadane and Wolfson 1996) and structural (that is, experts provided numerical values to certain parameters in the model; Wolfson and others 1996). Simply stated, if eight of 10 good habitat sites in our experience had attribute A, then the conditional probability of attribute A given good habitat was 0.80.

We assessed the accuracy of our habitat classification by comparing locations of active bald eagle nests in 1992 with predicted habitat quality. Cooperating State, Provincial, and Federal agencies provided active nest site locations to us *after* our aerial surveys and model development were completed; we did not know where any active bald eagle nests were located along the Great Lakes shorelines prior to our surveying and modeling. With the completed PATREC model (table 3), we also calculated posterior probabilities for a series of hypothetical habitat conditions (tables 4 and 5) to evaluate the relative influence of identified habitat attributes on overall habitat suitability under varying circumstances.

## Results

Our primary objective was to develop a Bayesian model of our aerial search image. This PATREC model consists of six habitat attributes composing that aerial search image: (1) tree cover, (2) proximity and (3) type/

amount of human disturbance, (4) potential foraging habitat/shoreline irregularity, and availability of suitable trees for (5) perching and (6) nesting (table 3). Attributes 1 and 2 are assessed first to estimate if further evaluation is appropriate. If conditions for these attributes are met or exceeded, habitat evaluation with our model proceeds using the conditional probabilities of the remaining functional components (attributes 3 through 6) to estimate overall probability of good, marginal, or unsuitable habitat under the observed conditions. Attributes 3 through 6 appear in the same order that they were assessed from the air; although after attributes 1 and 2, order in the model does not affect outcome. Type/amount of nearest human disturbance is partitioned into three levels to accommodate the influence of varying amounts of human activity on potential habitat evaluation. The conditional probabilities of good habitat for the last three attributes are weighted more heavily to stress the benefit of potential foraging areas and the critical importance of suitable perch or nest trees. All parameters in the model can be adequately estimated from the air with practice and experience. (See table 5 for sample calculations using this PATREC model.)

Of the 117 active bald eagle nests along the Great Lakes shorelines in 1992, 97 were in habitat our model classified as good (82 percent) or marginal (15 percent). Only 3 percent of the active nests occurred in habitat the model classified as unsuitable (Bowerman 1993). Yet, we classified 47 percent of the 10,596 km total Great Lakes shoreline surveyed as good habitat, 19 percent as marginal, and 34 percent as unsuitable (table 2). More active nests occurred in good habitat and fewer in unsuitable habitat than expected from the relative abundance of each class ( $X^2 = 2,970$ ,  $df = 2$ ,  $P < 0.001$ ; Bowerman and others, in press). No active bald eagle

**Table 3**—Pattern recognition (PATREC) model of the search image used to identify potential bald eagle nesting habitat during an aerial survey of the Great Lakes shorelines in 1992. Prior probabilities = Good, 0.68; Marginal, 0.27, and Unsuitable 0.05.<sup>a</sup>

Habitat attributes	Conditional probabilities <sup>b</sup>		
	Good	Marginal	Unsuitable
<b>1. Tree cover<sup>c</sup></b> >10% forested	0.99	0.99	0.01
<b>2. Proximity nearest human disturbance<sup>d</sup></b> >0.8 km from light to moderate human activity (attributes 3a and 3b), or >1.6 km from heavy human activity (attribute 3c)	0.99	0.99	0.01
<b>3. Type/amount nearest human disturbance</b>			
a. Light <sup>e</sup> - trails, undeveloped campgrounds, unimproved roads	0.55	0.25	0.20
b. Moderate <sup>f</sup> - buildings, paved roads, small boat docks/launches	0.40	0.45	0.20
c. Heavy <sup>f</sup> - cities, industry, extensive development, marinas	0.05	0.30	0.60
<b>4. Potential foraging habitat and/or shoreline irregularity</b> Presence of shallows, bays, marshes, small lakes, and/or Ratio of total shoreline to linear distance >2.0 <sup>g</sup>	0.90	0.60	0.20
<b>5. Potential perch trees</b> Suitable <sup>h</sup> perch trees ≥30 cm diameter at breast height (d.b.h.) ≤0.4 km from potential foraging area	0.98	0.60	0.30
<b>6. Potential nest trees</b> ≥3 suitable <sup>i</sup> nest trees, ≥61 cm d.b.h. if coniferous or ≥46 cm d.b.h. if deciduous, Dominant (supercanopy) or near edge (of stand, along shore)	0.98	0.60	0.30

<sup>a</sup> Prior probabilities, for habitat remaining after approximately 90 percent of the unsuitable class was removed by steps 1 and 2, were estimated by planimetrically measuring the approximate length of shoreline in each habitat class for each Great Lake, then calculating class totals and the relative percentage of each (table 2).

<sup>b</sup> Conditional probabilities of each habitat attribute given the presence of each habitat suitability class.

<sup>c</sup> If tree cover is >10 percent, continue to step 2 because of the high probability (0.99) of the habitat being marginal to good. If tree cover is ≤10 percent, do not continue because of the low probability (0.01) that the habitat will be suitable.

<sup>d</sup> If nearest human disturbance is either >0.8 km from light to moderate activity or >1.6 km from heavy activity, continue to step 3 because of the high probability (0.99) of the habitat being marginal to good. If nearest human disturbance is ≤0.8 km or ≤1.6 km, respectively, do not continue because of the low probability (0.01) that the habitat will be suitable.

<sup>e</sup> Use the light category when human activity is totally absent.

<sup>f</sup> All attributes but moderate and heavy human disturbance have a positive influence on the probability of good eagle nesting habitat. Thus, the conditional probability of other attributes decreases as habitat quality decreases; but the probability of detrimental attributes generally increases. However, moderate human disturbance >1.6 km away is variable. It has slightly more influence in marginal habitat than good but has little impact on habitat unsuitable because of other attributes lacking.

<sup>g</sup> Total shoreline ÷ linear distance. Total shoreline includes the Great Lake shore plus that of any islands, bays, marshes, interior lakes, streambanks or riverbanks, and so forth, within the survey window. Linear distance is the length of a straight flight path parallel to shore across the survey window, that is, 3.2 km (fig. 3).

<sup>h</sup> Suitable perch trees typically have exposed or open branching with good views and accessibility.

<sup>i</sup> Suitable nest trees have accessible, sufficiently large branching and structure at or above canopy height to support an eagle nest.

nests occurred in habitat eliminated from consideration by our first two model attributes.

We calculated posterior probabilities for a series of suboptimal, hypothetical habitat conditions (not all attributes present or at suitable levels for bald eagle nesting; table 4) after attributes 1 and 2 in our PATREC model (absence of tree cover and proximity of human disturbance; table 3) eliminated approximately 90 percent of the unsuitable habitat from further analysis. Sample calculations are outlined in table 5. The estimated probability of good habitat when all habitat attributes were optimal was 96 percent, and when none of the attributes were present, 0 percent. Moderate human disturbance depressed good and raised marginal habitat probabilities less than 6

percent, but heavy disturbance resulted in a shift of greater than 32 percent. Absence of foraging habitat/irregular shoreline reduced probabilities of good and marginal habitat 17 to 18 percent. Lack of sufficient trees for perching and nesting, considered separately or in combination, had the greatest impact (54 to 94 percent) on the estimated probability of good and marginal habitat by the PATREC model. The probability of marginal or unsuitable habitat increased with the absence of key habitat attributes such as perches, nest trees, or potential foraging areas. This suggests that addition or restoration of these attributes might substantially improve habitat quality. All combinations of absent or suboptimal attributes depressed the probability of good habitat and raised probabilities of

**Table 4**—Estimated posterior probabilities (x100) for a series of hypothetical, suboptimal habitat conditions, calculated with a pattern recognition (PATREC) model of the survey image used to identify potential bald eagle nesting habitat during an aerial survey of the Great Lakes shorelines in 1992. (Adequate tree cover and distance from human disturbance are assumed.<sup>a</sup>)

Habitat conditions <sup>b</sup> (from PATREC model, table 3)	Habitat class		
	Good	Marginal	Unsuitable
1. Best case, all attributes satisfied	95.6	4.3	0.1
2. Moderate disturbance	89.9	10.0	0.1
3. Heavy disturbance	62.0	36.9	1.1
4. No potential foraging/irregular shoreline	77.5	21.0	1.5
5. No suitable perch trees	39.4	58.1	2.5
6. No suitable nest trees	39.4	58.1	2.5
7. No suitable perch or nest trees	1.8	85.3	12.9
8. No perch trees/no additional foraging	8.2	72.9	18.9
9. No foraging/moderate disturbance	58.9	39.5	1.6
10. No foraging/heavy disturbance	19.1	68.3	12.6
11. No perch or nest trees/no foraging	0.1	52.3	47.6
12. Worst case, no attributes satisfied	0.0	30.6	69.4

<sup>a</sup> Lack of tree cover and proximity of human disturbance (attributes 1 and 2; table 3) eliminated approximately 90 percent of the unsuitable Great Lakes shoreline habitat from further evaluation.

<sup>b</sup> With the exception of cases 1 and 12, only absent or suboptimal habitat attributes are listed; all other attributes were assumed to be satisfied, that is, optimal.

marginal and unsuitable habitat, more than when the same attributes were considered individually.

## Discussion

PATREC is a little known but potentially valuable analytical tool for both the research ecologist as well as the resource manager. Although our example deals only with Great Lakes bald eagle nesting habitat, PATREC is not specific to species, pattern, or locale. A significant advantage of PATREC as an instrument of Bayesian inference lies in its ability to incorporate and quantify preexisting or subjective, experience-based information (Edwards 1996). PATREC provides a means of incorporating *a priori* scientific judgment into hypothesis testing (Reckhow 1990). The resultant model indirectly communicates that prior experience to those less familiar with the target species or ecological system, and thereby facilitates further investigation or management. “Pattern recognition” mimics the researcher’s thought process by first evaluating current sample conditions against similar conditions experienced previously, and then estimating the probability to which the current sample conditions fit the previously experienced

pattern (Williams and others 1977). PATREC has potential utility in a wide range of applications, from exploratory research analyses to applied resource modeling. This Bayesian technique allows decision theory to be applied to ecological problems while accommodating uncertainty in the analyses (Wade 2000).

The most convincing evidence for any statistical methodology is the use of real data in a verifiable case study where the population truth is known (Edwards 1996). Survey data in our Great Lakes PATREC model represent actual habitat, and the distribution of concurrently active bald eagle nest sites was verifiable from independent nesting surveys. The comparison between our PATREC habitat classifications and current bald eagle nest sites in 1992 showed that the model correctly classified most active nesting habitat and was sensitive to habitat variation. It underestimated the amount of good habitat in 1992 and overestimated the amount of marginal habitat. This may be a result of random variation or may suggest the omission of another important factor. Therefore, we recommend further refinement of habitat attributes to better identify and quantify specific areas along the Great Lakes shorelines that could be suitable for bald eagle nesting. The aerial surveys and PATREC model failed to identify four areas along Lake



these potential sources of bias were minimized by the extent of our collective eagle experience, the check and balance of five independently developed opinions, our assessing only observable habitat features and their predictive probabilities, and our use of frequent feedback from conditional and unconditional assessments on hypothetical data in model development (Wolfson and others 1996).

Utilizing PATREC to organize the interpretation of an experience-based, aerial search image includes subjectivity throughout the model. In traditional Bayesian analysis (Edwards and others 1963, Ellison 1996), subjective input is typically focused in the prior probabilities. Nonetheless, even though conditional probabilities are best derived from a frequentist analysis when feasible, if empirical data are lacking, two alternatives for developing them are literature review and expert opinion (Flather and Hoekstra 1985; Kling 1980; Seitz and others 1982; Williams and others 1977). Both approaches invoke subjectivity, either on the part of the reviewer or the experts. Although we relied heavily on expert opinion to estimate our conditional probabilities because sufficient empirical data were lacking, those opinions were based on frequencies of eagle nests observed in various habitat conditions in other areas over the course of our experience. There was little variability among our independently developed perceptions. In our model, these opinion-based frequencies were tempered with empirical data from the actual survey; that is, the frequency of each habitat attribute given the observed presence of each habitat class. Furthermore, although the original determination of habitat suitability classes was experience-based, planimetric measurement of shoreline in each class was empirical. This empirical input into both the prior and conditional probabilities led to an improved model specifically calibrated to the Great Lakes region.

## Management Implications

Our purpose in developing the PATREC model was to take advantage of Bayesian procedures to organize and consistently structure the essentially subjective, experience-based search image that made our 1992 exhaustive survey possible. In this sense, our model's posterior probability estimates are still subjective. However, with this model instead of just the "black-box" opinions of experts, any biologist—no matter how naive or inexperienced with bald eagles—has a set of explicit, proven, replicable criteria for evaluating potential nesting habitat. Only minimal training or experience is required to

estimate distances, tree cover, and size classes at the level of precision necessary for the model. This PATREC model is specific to species, season, location, and survey technique. It was calibrated to evaluate bald eagle nesting season habitat within 1.6 km of the Great Lakes shorelines during a low-level, aerial survey. However, either a terrestrial or nearshore lake survey in conjunction with recent aerial photographs could substitute for using an aircraft.

Because prior probabilities were calculated for use on all five Great Lakes, our model will tend to underestimate the probability of good habitat on the upper lakes where good habitat is abundant (Superior, Michigan, Huron), and overestimate good habitat on the lower lakes where such habitat is limited (Erie and Ontario; Bowerman and others, in press). The model, much like any human aerial surveyor covering great lengths of unfamiliar habitat, will not pick up unusual pockets of good habitat, such as the isolated, relatively undisturbed, lone nest tree in a coastal marsh. Nonetheless, our model provides a basis for future comparison, modification, and replication; our habitat results (Bowerman and others, in press) also offer a bench mark for long-term ecosystem monitoring. Even without further refinement, this PATREC model will be useful in the continuing evaluation and management of shoreline habitat because it provides insight into the number, type, and relative importance of key habitat attributes associated with bald eagle nesting along the Great Lakes.

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