Predicting Rare Orchid (Small Whorled Pogonia) Habitat Using GIS

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Abstract

Isotria medeoloides *(Pursh) Raf., commonly known as the small whorled pogonia, is the rarest orchid in eastern North America, north of Florida. Although it has a wide ranging distribution, more than 80 percent of the known plants are found in New Hampshire and Maine. A geographic information system (GIS) was used to facilitate locating potential habitat for* Isotria medeoloides *in the two states. Field characteristics, including physiography, soils, and forest and herbaceous cover, were evaluated at 27 extant locations of the orchid. Site locations were digitized, and general habitat characteristics at each site were identified using the GIS. Digital habitat information included topographic data derived from the USGS Digital Elevation Model, soil types from the USDA Natural Resource Conservation Service, and spectral data from Landsat Thematic Mapper. Intervals within each habitat parameter were defined and weighted according to their frequency of occurrence at extant sites. Two predictive GIS overlay models were developed: an equal weight model and a chi-square model. In the first scenario, each habitat characteristic was weighted equally. In the second, the importance of each habitat parameter was evaluated with a chi-square test of habitat features at sites with and without orchids. As a result of the chi-square evaluation, the following general characteristics were determined to be positively associated with small whorled pogonia sites: soils with a pan layer, percent slopes between 11 and 17 percent, and a digital reflectance greater than 68 for the near infra-red band of Landsat Thematic Mapper data. To determine the effectiveness of each model in predicting potential habitat, field surveys of eight USGS topographic quadrangles in New Hampshire and the town of Acton, Maine were conducted. Nine previously undiscovered populations of* Isotria medeoloides *were found. The accuracy of the models was assessed at 23* Isotria medeoloides *populations, 13 of which were excluded from model development. The equal weight model correctly predicted 57 percent of the sites as potential habitat, and the chi-square model correctly predicted 78 percent of the sites. The GIS provided a useful tool for combining ecological habitat characteristics to successfully predict potential habitat for* Isotria medeoloides.

Introduction

Species are becoming extinct at what may be the greatest rate in the past 65 million years (Wilson, 1988). The majority of species losses are occurring due to the destruction of natural habitats and their conversion to other uses (Murphy, 1988). To slow continued losses, there is a need for increased knowledge of the distribution, biology, and habitat requirements of all species.

In New England, one rare species threatened primarily by habitat loss is *Isotria medeoloides* (Pursh) Raf., commonly known as the small whorled pogonia. *Isotria medeoloides* is an herbaceous, perennial orchid. It is characterized by a whorl of five or six leaves at the top of a glabrous, pale-green, hollow stem. A single, yellowish-green flower, or occasionally two, may bloom from the center of the leaf whorl.

Isotria medeoloides was discovered by Frederick Pursh in 1814 and has since been considered the rarest orchid east of the Mississippi, excluding Florida (Gleason, 1952; Luer, 1975; Gleason and Cronquist, 1991). While known historically from 60 sites (49 counties in 17 states and one county in Ontario), only 16 extant sites were known in 1980 (U.S. Fish and Wildlife Service, 1980). As a result, in October of 1982, the U.S. Fish and Wildlife Service designated this small, woodland orchid as federally Endangered (U.S. Fish and Wildlife Service, 1982).

Since its listing, scientists have studied the habitat requirements of *Isotria medeoloides* to better understand existing populations and to locate additional occurrences (Gaddy, 1985; Rawinski, 1986; Mehrhoff, 1989). Due in part to their successes, in 1992 a total of 93 extant sites were known (U.S. Fish and Wildlife Service, 1992). Of this total, more than one half of the sites occurred in New Hampshire and Maine. Furthermore, the largest *Isotria medeoloides* sites were located in these two states, and accounted for over 80 percent of all known plants (U.S. Fish and Wildlife Service, 1992). The predominance of *Isotria medeoloides* in New Hampshire and Maine suggests that the orchid may be adapted to specific habitat conditions that exist primarily in this portion of its range.

This study was undertaken to investigate the ecology and distribution of *Isotria medeoloides* populations in New Hampshire and Maine, and to predict potential habitat for the orchid. The specific objectives of this study were (1) to examine *Isotria medeoloides* habitat in New Hampshire and Maine to determine if general landscape-level characteristics were associated with extant sites, and (2) to utilize a GIS model to identify combinations of these important habitat characteristics to locate potential *Isotria medeoloides* habitat.

Soil type, physiography, forest cover, and site disturbance history may be among the most important habitat indicators in New Hampshire and Maine (Rawinski, 1986). The soils which underlie *Isotria medeoloides* sites are generally acidic, sandy loams (Mehrhoff, 1989; Vitt, 1991; Ware, 1991). Many of the soils contain an impervious layer, often a fragi-

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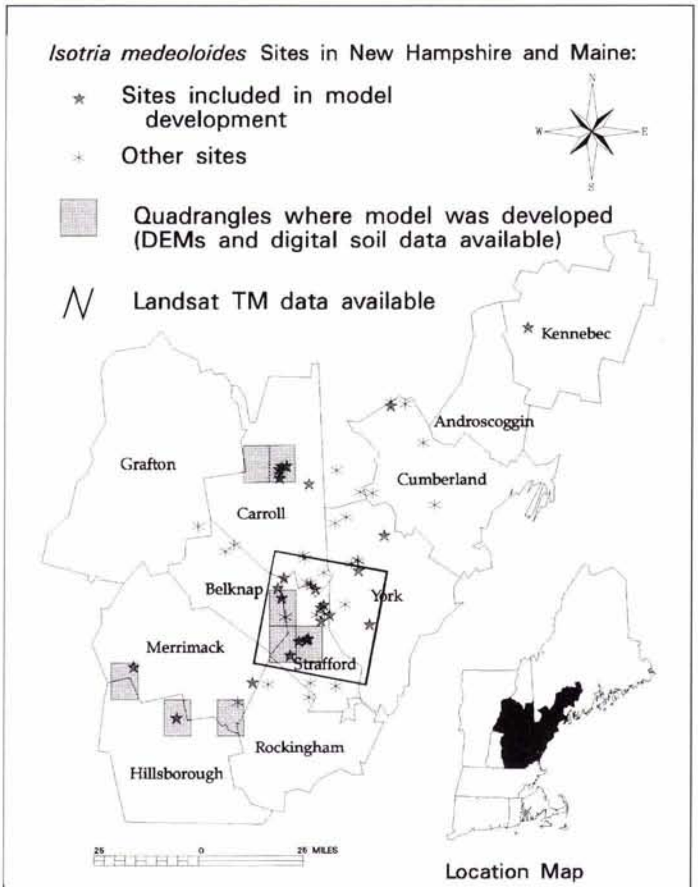

Figure 1. Study area.

pan, beneath the surface. The impervious layers prevent downward percolation of water and increase surface runoff (Rawinski, 1986). In hilly terrain, numerous ephemeral runoff channels occur at the soil surface. Rawinski (1986) believed that these runoff areas provided ideal *Isotria medeoloides* habitat; many of the plants that he observed in New Hampshire and Maine grew within or beside these drainage areas.

The slope at *Isotria medeoloides* sites may contribute to providing preferred orchid habitat. In New Hampshire and Maine, Rawinski (1986) observed that many sites occurred on slopes of 8 to 15 percent at the base of steep slopes or on benches at mid-slope positions. In an examination of 11 sites, Mehrhoff (1989) measured slopes of 0 to 30 percent. These sites were generally situated in flat areas at the base of slopes, though some were on steeper mid-slope positions or ridgetops.

The aspect at *Isotria medeoloides* sites is variable. Mehrhoff (1989) found a range of aspects between 0 and 180 degrees. Rawinski (1986) suggested that aspect may only be important at the extremes of *Isotria medeoloides* range. In northern New Hampshire, *Isotria medeoloides* may be limited to south facing slopes because north facing slopes may be too cold.

Most sites are located in forests of mixed deciduous or mixed deciduous/coniferous species (Brackley, 1985; Rawinski, 1986; Mehrhoff, 1989; Ware, 1991). It was once believed that *Isotria medeoloides* preferred an association with *Fagus grandifolia* (American beech) (Eames, 1926). However, Mehrhoff's work (1989) suggested that reliable forest indicators did not exist. Associated species are generally oriented regionally, though *Acer rubrum* (red maple) and *Quercus rubra* (red oak) are found throughout the range of *Isotria medeoloides*. The herbaceous component of the forest is comprised of common herbs, ferns, and, occasionally, other orchids.

Land-use history and forest structure indicate that *Isotria medeoloides* inhabits mid-successional forests. Many of the sites are second- or third-growth forests which were initially cleared for agricultural or pastoral uses (Mehrhoff, 1989; Vitt, 1991; Ware, 1991). At several sites in Virginia (Ware, 1987), and at one site in New Hampshire (Brumback and Fyler, 1983), the ages of the trees have been estimated to be between 45 and 80 years. Gaps in the canopy which cause an increase in light availability, such as blowdowns, logging roads, and streams, may benefit *Isotria medeoloides*. Many sites are found near these types of openings (Gaddy, 1985; Mehrhoff, 1989; Brackley-Tolman, 1991).

To better understand the habitat requirements of *Isotria medeoloides* and to facilitate locating additional populations in New Hampshire and Maine, this study utilized a geographic information system (GIS) to construct a spatial habitat model for the orchid. GIS habitat models have been demonstrated to be powerful, cost-effective methods for identifying potential habitat of animal species (Scepan and Blum, 1987; Agee *et al.*, 1989; Breininger *et al.*, 1991; Gagliuso, 1991; Pereira and Itami, 1991; Hutchinson *et al.*, 1992; Clark *et al.*, 1993). Although GIS models for individual plant species are less common (Cherrill *et al.*, 1995), plant communities have been identified with remotely sensed satellite data and ancillary GIS data layers (Schriever, 1992; Lauver and Whistler, 1993).

In these predictive habitat models, habitat characteristics at known species locations were assessed and univariate analyses, such as the chi-square technique, were commonly used to determine which habitat characteristics were most important to each species (Agee *et al.*, 1989; Gagliuso, 1991; Pereira and Itami, 1991; Hutchinson *et al.*, 1992; Stoms *et al.*, 1992; Clark *et al.*, 1993). Preferred habitat characteristics were then weighted higher than those which were avoided (Agee *et al.*, 1989; Hutchinson *et al.*, 1992), and maps of each characteristic were overlaid to determine where combinations of important parameters co-occurred.

Potential habitat maps were field evaluated to determine the accuracy of the predictive models. Factors contributing to model errors were assessed. These include the researcher's ability to correctly define potential habitat, and inaccuracies and limitations associated with digital habitat data. Mapping errors related to map scale, date of mapping, and minimum mapping unit (Stoms *et al.*, 1992) were evaluated.

Methods

The study area includes the majority of southern New Hampshire, as well as the four southernmost counties in Maine (Figure 1). The area was chosen to include the known historic and extant locations of *Isotria medeoloides* in New Hampshire and Maine.

The climate is temperate, being modified by the nearby Atlantic Ocean. The elevation ranges from sea level on the coast to about 1000 metres in the southern portion of the White Mountains. However, the general elevation varies from 150 to 450 metres. Much of the terrain is hilly to mountainous, particularly in the northern part of the study area. The major parent materials in the study area are glacial till, glaciofluvial deposits, marine and lacustrine sediments, and organic matter. Site specific soil characteristics result from a combination of parent material, bedrock mineralogy, and topographic position.

The forests of the region occupy the transition hardwoods-white pine-hemlock zone (Westveld *et al.*, 1956). The forests are dominated by second- and third-growth stands, as a result of over two centuries of human influence and activity.

To develop a general understanding of the habitat at existing *Isotria medeoloides* sites, the ecological characteristics at 27 sites were investigated during the summer of 1992. Topographic features, including percent slope and aspect, were measured with a clinometer and a compass, respectively. Associated tree, shrub, and herb species were identified, and a soil profile was examined for the presence of a restrictive layer, such as a fragipan.

GIS Data Collection

The locations of the 27 previously surveyed *Isotria medeoloides* field sites were compiled on 1:24,000-scale USGS paper topographic maps with information from field surveys, and with information supplied by the New Hampshire and Maine Natural Heritage Programs. Mylar quad overlays were used to digitize the site locations. These locations were then plotted and verified for accuracy. Data were converted to New Hampshire state plane coordinates, North American Datum (NAD) 1983. ARC/INFO software, version 3.4d and version 6.1.1 (ESRI, 1991), was used to process all digital data.

Field assessments provided specific data about the habitat at *Isotria medeoloides* sites. However, site specific information was not available in digital form. Therefore, generalized habitat layers, which were available digitally, were utilized in the model. These layers included physiographic features, soils, and forest cover. None of these data were available for the entire study area. Therefore, manual, map-based measurements which corresponded to digital measurements were developed, or a combination of digital and analog sources were utilized.

Digital topographic data (DEMs) were not available at all *Isotria medeoloides* sites. As a result, it was necessary to develop manual slope and aspect calculating methods with a resolution similar to the DEMs. The agreement between manual and digital measurements was then assessed.

A standard hydrologic method (referred to as the grid method) was used to calculate average slope (Horton, 1932). A 4 by 4 grid, where each grid line was 6.35 mm (0.25 in.) in length (or 500 feet in map units at 1:24,000 scale), was overlaid on a USGS topographic map at the center of each *Isotria medeoloides* site. The grid was placed on the map in a north/south orientation. The number of intersections between grid lines and contour lines was determined. Average slope was calculated from the following formula:

$$s = (N * Z * 1.57)/L$$

where s is the slope (%), N is the number of intersections, Z is the contour interval on the map (feet), and L is the total length of the grid lines represented in map units (4000 feet). The constant of 1.57 was necessary to account for the different angles at which the grid lines crossed the contour lines.

An average value for aspect was estimated at each of the *Isotria medeoloides* field sites by measuring the compass bearing of a line drawn perpendicular to the contour lines. To identify which slopes and aspects were most frequent, the means, standard deviations, and percentiles were calculated for each topographic layer.

Digital slope and aspect data layers were derived from 30-metre resolution DEM data. The DEMs were converted to an ARC/INFO format, transformed to a lattice file, and filtered to smooth sharp peaks or discordant points. The lattice was generalized to a resolution of 63.61 metres to better approximate the resolution of the slope measurements generated using the grid method (Horton, 1932). Algorithms within ARC/INFO were used to generate slope and aspect data layers from the lattice file (ESRI, 1991). Six classes of slope and five classes of aspect were specified based on the previously measured frequency of occurrence of these map-based characteristics at extant *Isotria medeoloides* sites.

The agreement between the map derivation of slope and the DEM derivation of slope was assessed at a systematic sample of 189 locations on two USGS quadrangles. Values of both the map and the digital slope derivations were assigned to one of three broad classes. These classes were determined from the distribution of topographic characteristics at the *Isotria medeoloides* field sites. Three classes were chosen to ensure that enough samples from each method would be assessed for each class. For each site, the class predicted by the topographic derivation and the digital derivation was compared. Standard accuracy assessment procedures from remote sensing (Congalton, 1991) were used to assess the agreement between the two measurements.

Soil types were mapped by the USDA Natural Resource Conservation Service (formerly the Soil Conservation Service) at 1:20,000 or 1:24,000 scale for each of the counties in the study area. The minimum mapping unit is generally 1.6 hectares in size. However, in some extensive forested areas, it is as large as 16 ha. In New Hampshire, digital soils data were provided by the New Hampshire Geographically Referenced Analysis and Information Transfer System (GRANIT) for the counties of Strafford, Rockingham, Carroll, and Hillsborough. In Maine, digital soil data were provided by the NRCS for the town of Acton, Maine.

The locations of the *Isotria medeoloides* field sites were overlaid with the digital (when available) or paper soil maps to identify which soil types were present. Because of the suspected importance of impervious layers to *Isotria medeoloides* distribution, the frequency of occurrence of restrictive layers was determined from the soil type description.

Forest cover was derived from Landsat Thematic Mapper (TM) data. An area of 1536 by 1536 pixels (or approximately 212,500 ha) was subset from an 8 September 1990 Landsat TM scene (Path/Row: 12/30; Scene Id: Y5238214463). Sixteen orchid sites, consisting of 29 distinct sub-population locations, occurred within this region.

The objective for using the TM data was to rank forest areas according to their potential for supporting *Isotria medeoloides*. This was achieved by identifying the digital values of the TM data characteristic of *Isotria medeoloides* sites. First, the bands necessary to classify the data into forest and non-forest land were determined. Second, the band which best distinguished *Isotria medeoloides* sites was identified. Finally, digital numbers were evaluated to determine which range of values was most common at orchid sites.

Analysis of the TM data was divided into six major steps: (1) rectification, (2) band generation, (3) band selection, (4) classification, (5) digital number analysis, and (6) raster-to-vector conversion. All image processing utilized ERDAS Version 7.5 software (ERDAS, 1991). The raster-to-vector conversion process was performed with ARC/INFO Version 6.1.1 (ESRI, 1991).

To overlay the imagery with other digital data layers, a geometric rectification was performed. A first-order transformation was computed with an RMS error of 0.496 pixels. Sixteen ground control points, including at least one point from each corner of the image, were used to rectify the image data to the New Hampshire state plane coordinate system. A nearest-neighbor resampling approach was used to perform the rectification because this approach minimizes the effects of resampling on pixel spectral values (Campbell, 1987; Herr and Queen, 1993).

Once the image was rectified, two derivative spectral bands were generated. The first derivative band (PC1) was created from a principal components analysis of the three visible bands. The second derivative band (TM4/3) was the 4/3 band ratio.

To determine which bands maximized the spectral distinction between forest and non-forest land, spectral pattern

analyses and divergence tests were employed (Stenback and Congalton, 1990). The combination of bands 5, PC1, and TM4/3 was used to conduct a supervised classification because it included a band or band derivative from each of the visible, near-infrared, and mid-infrared regions and because it differentiated among classes in the spectral pattern analyses. Land-cover types, including forest, urban, agriculture/open, and water, provided training areas for the classification.

Once non-forest areas were masked from the data set, band discrimination tests were employed to determine which band best identified *Isotria medeoloides* sites. The mean digital reflectance for each band was calculated at 29 known *Isotria medeoloides* locations. Each of the site location means was used to calculate combined means and percentile distributions.

For each band, the percentile distributions of digital reflectance at orchid sites were graphed with the percentile distributions of digital reflectance for 71 randomly selected forest sites where it was assumed that *Isotria medeoloides* did not occur. Due to the rarity of *Isotria medeoloides*, it was felt that this assumption was valid. Furthermore, studies of rare animals habitats have made similar assumptions (Agee *et al.*, 1989; Gagliuso, 1991). A spectral pattern analysis which compared the mean digital reflectance values of the 21 largest *Isotria medeoloides* locations to the random forest locations was also generated.

The percentile distribution of digital reflectance for band 4 was used to weight the digital numbers in the imagery to reflect their potential to indicate *Isotria medeoloides* habitat. Band 4 was chosen because it best discriminated between sites where orchids were present and sites where orchids were absent. A weighting scheme with three categories was developed. The digital numbers were recoded to reflect the three category weighting scenarios, and a 3 by 3 majority filter was applied to smooth the speckling in the data. A polygon coverage was generated from the forest cover data.

Model Creation and Accuracy Assessment

Once each of the digital habitat layers was generated, two overlay models were created to identify potential habitat. The first model employed a simple overlay procedure where each characteristic received equal weight. The second scenario utilized a weighting scheme based on a chi-square test of the significance of each characteristic at extant *Isotria medeoloides* sites.

In the equal weighting scenario, the four digital data layers – slope, aspect, soils, and forest cover – were overlaid. The frequency distributions of habitat characteristics at *Isotria medeoloides* sites were used to identify the optimum ranges of each characteristic. For each habitat characteristic except forest cover, the optimum habitat was defined as the range in the center of the distribution in which 50 percent of the *Isotria medeoloides* sites were found. Due to the variability of forest cover, the optimum habitat for this data layer was expanded to include the central range of digital numbers in which 80 percent of the *Isotria medeoloides* sites were found. Highest potential habitat was identified where the optimum range for each of the characteristics co-existed. High potential habitat was identified where the optimum range for three characteristics co-existed with a sub optimum range for the fourth characteristic.

In the second scenario, a chi-square statistic was used to weight each of the habitat characteristics. The chi-square statistic provided an indication of how strongly the distribution of characteristics at *Isotria medeoloides* sites varied from the distribution of those characteristics on the landscape. A large chi-square statistic indicated an association between *Isotria medeoloides* sites and a particular habitat characteristic.

To perform the chi-square analysis, each of the habitat variables was divided into three categorical classes. For slope, aspect, and digital number, the classes were defined as follows: class 1, where 25 percent of the sites were found; class 2, where 50 percent of the sites were found; and class 3, where the remaining 25 percent of the sites were found. Soils data were already in a categorical format; the three categories were pan, shallow to bedrock, and deep or unsuitable.

The value of each habitat characteristic was determined at sites with and without orchids. Slope, aspect, and soil type were assessed from digital or paper map data at the *Isotria medeoloides* field sites. Digital reflectance was assessed at the *Isotria medeoloides* locations represented with the TM data. Seventy-one randomly generated forested sites, which were assumed to be without orchids, were evaluated for all four habitat characteristics. There were nearly three times the number of sites without orchids as there were sites with orchids to increase the likelihood of getting a more representative sample of the habitat characteristics on the landscape (Pereira and Itami, 1991). The distribution of each of the characteristics was compared at sites with and without orchids to calculate the chi-square statistic. The proportional importances based on the computed chi-square statistic were used to weight the significant habitat parameters.

The habitat characteristic data layers were overlaid, and the weights of the individual layers were totaled to yield an overall score for each polygon in the composite map. Polygons which had the highest possible overall score were defined as highest potential habitat. Polygons with the next two highest scores were defined as high potential habitat.

Both models were tested on eight 7.5-minute USGS quadrangles in New Hampshire, and the town of Acton, Maine. Due to the limited size of the TM dataset, forest-cover information was only available for three of the quadrangles. In Acton, Maine forest-cover data were utilized; however, slope and aspect information was estimated manually due to the lack of digital topographic data for this region.

Once the GIS analysis was completed, approximately 24 field days were devoted to searching for populations of *Isotria medeoloides* in the eight quadrangles in New Hampshire and the town of Acton, Maine. Site selection for model evaluation was stratified based on habitat potential. Fifty locations with habitat potential were searched. Locations were approximately equal in size; large areas were divided into multiple smaller units. While sites without habitat potential were not quantitatively evaluated, considerable acreage of very low potential habitat was surveyed while travelling to sites with high and highest habitat potential. The accuracy of each model was assessed at 23 *Isotria medeoloides* sites. Ten of the sites were included in model development, and 13 of the sites were not included in model development.

Results

The ecological characteristics sampled at *Isotria medeoloides* sites provided a general measure of field conditions. The mean aspect was 157°, with a standard deviation of 100°. Percent slopes were low, ranging from 0.87 to 12.28, with a mean of 4.17 and standard deviation of 2.74. Common tree species included *Acer rubrum* (red maple), *Pinus strobus* (white pine), *Tsuga canadensis* (eastern hemlock), and *Quercus rubra* (red oak). A suite of common herbaceous and shrub species was also present. Three classes of restrictive layers were identified in soils at the 27 sites. Twenty-three percent of the sites had deep soils and lacked an impervious layer, 27 percent had shallow bedrock, and 50 percent had a pan layer.

GIS Data Layers

Utilizing the Horton (1932) manual slope measurement technique, six classes of average percent slope were identified

and weighted according to their distributions at the *Isotria medeoloides* field sites (Table 1). Fifty percent of the *Isotria medeoloides* sites had average slopes between 10.99 percent and 17.27 percent. Therefore, this category of slope was weighted with a value of 50. Average slopes which occurred at lower frequencies were weighted with lower values.

The agreement between Horton's (1932) grid measure of average slope and the digital derivation of average slope at a systematic sample of 189 locations is portrayed in Table 2. In the table, the slope classes that were defined on the basis of the distribution of *Isotria medeoloides* were collapsed into three broader classes. The majority of samples occurred in class 1 & 2, and the minority occurred in class 4, 5 & 6. The poorest agreement between measures occurred for class 3: the range of average slopes that occurred at 50 percent of the *Isotria medeoloides* sites. The producer's accuracy for class 3 was 42 percent, and the user's accuracy for class 3 was 64 percent. The overall agreement between the manual and the digital slope measurements was 74 percent. Plate 1 displays the slope classes for one of the quadrangles in New Hampshire (Quadrangle 1).

Based on map-derived measurements, five classes of aspect were identified and weighted according to their frequency at the *Isotria medeoloides* field sites (Table 3). Fifty percent of the sites had average aspects between 80 and 240 degrees. Aspects generated for Quadrangle 1 are displayed in Plate 1.

The distribution of soil impervious layers compiled from NRCS maps for the *Isotria medeoloides* field sites is presented in Table 4. Fifty-nine percent of the *Isotria medeoloides* sites had pan layers, 22 percent were shallow to bedrock, and 19 percent lacked an impervious layer. The overall agreement between NRCS measures of impervious layers and field observations was 56 percent, and the KHAT agreement was 25.2 percent. For soils with pan layers, the producer's accuracy was 71 percent and the user's accuracy was 63 percent. The soils in Quadrangle 1 are displayed in Plate 1.

Spectral pattern analyses of TM data distinguished the combination of bands 5, PC1, and TM4/3 as the best discriminator between forest and non-forest land. Within forested areas, three bands maximized the separability between orchid and non-orchid sites: band 4, band 5, and TM4/3. Spectral pattern analyses and cumulative frequency graphs indicated that band 4 provided the greatest separation between the two types of sites. The frequency distribution of digital numbers for band 4 at the *Isotria medeoloides* locations on the imagery is displayed in Table 5. Eighty percent of the locations had digital numbers between 68 and 93. The frequency of digital numbers in Quadrangle 1 is displayed in Plate 1.

TABLE 1. DISTRIBUTION OF AVERAGE PERCENT SLOPE AT THE *Isotria medeoloides* FIELD SITES.

Class	Range of values	Frequency at sites	Weight
1	$x <= 7.85$	10%	10
2	$7.85 < x <= 10.99$	15%	15
3	$10.99 < x <= 17.27$	50%	50
4	$17.27 < x <= 19.625$	15%	15
5	$19.625 < x <= 21.20$	10%	10
6	$21.20 < x$	0%	0

TABLE 2. CONFUSION MATRIX SHOWING SLOPE CLASSES DETERMINED FROM THE HORTON METHOD VS. SLOPE CLASSES DETERMINED FROM A 63.61-METRE LATTICE.

	grid				
	Class	1&2	3	4,5&6	Total
63.61m latt.	1&2	96	24	1	121
	3	10	25	4	39
	4,5&6	0	11	18	29
	Total	106	60	23	189

Slope Classes

- Class 1 & 2: x<=10.99
- Class 3: 10.99<x<=17.27
- Class 4, 5 & 6: 17.27<x

Overall Accuracy:

139/189 = 74%, KHAT = 52.5%

Producers Accuracy

- Class 1 & 2 = 96/106 = 91%
- Class 3 = 25/60 = 42%
- Class 4, 5 & 6 = 18/23 = 78%

Users Accuracy

- Class 1 & 2 = 96/121 = 79%
- Class 3 = 25/39 = 64%
- Class 4, 5 & 6 = 18/29 = 62%

TABLE 3. DISTRIBUTION OF ASPECT (DEGREES FROM TRUE NORTH) AT THE *Isotria medeoloides* FIELD SITES

Class	Range of values	Frequency at sites	Weight
1	$x <= 42$	10%	10
2	$42 < x <= 80$	15%	15
3	$80 < x <= 240$	50%	50
4	$240 < x <= 323$	15%	15
5	$323 < x <= 360$	10%	10

TABLE 4. DISTRIBUTION OF SOIL IMPERVIOUS LAYERS AT THE *Isotria medeoloides* FIELD SITES.

Class	Frequency at sites	Weight
deep	19%	19
shallow	22%	22
pan	59%	59
other	0%	0

TABLE 5. DISTRIBUTION OF DIGITAL NUMBERS FOR BAND 4.

Class	Range of values	Frequency of sites	Weight
1	$0 < x <= 68$	10%	10
2	$68 < x <= 93$	80%	80
3	$93 < x$	10%	10
4	$x = 0$	0%	0

Model Creation and Accuracy Assessment

Highest and high potential habitat are displayed for Quadrangle 1 in Figure 2. The model predicted 125 ha (0.9 percent of the quadrangle) as highest potential habitat, and 492 ha (3.5 percent of the quadrangle) as high potential habitat.

The results of the chi-square analysis for each of the habitat variables is presented in Table 6. The chi-square values for soils, slope, and digital number were significant with at least 99 percent probability. The chi-square statistic for aspect was not significant.

Isotria medeoloides appeared to prefer specific classes within each of the significant habitat characteristics. With respect to soil characteristics, *Isotria medeoloides* showed a preference for sites with a pan layer, because the number of observed sites with pans (16) was greater than the expected number of sites with pans (9.4). *Isotria medeoloides* sites were negatively associated with deep soils and had no preference for soils shallow to bedrock. There were more *Isotria medeoloides* sites on Class 3 slopes (13) than was expected (8), and fewer sites on Class 1 & 2 (8) than were expected (14.6). The chi-square test indicated that *Isotria medeoloides* showed no strong preference or avoidance of slopes in Class 4, 5 & 6. This is somewhat misleading, however, because this category is a conglomerate of three individual classes. There were no sites found in slope Class 6. The digital number (DN) values in Classes 2 and 3 were more prevalent at *Isotria*

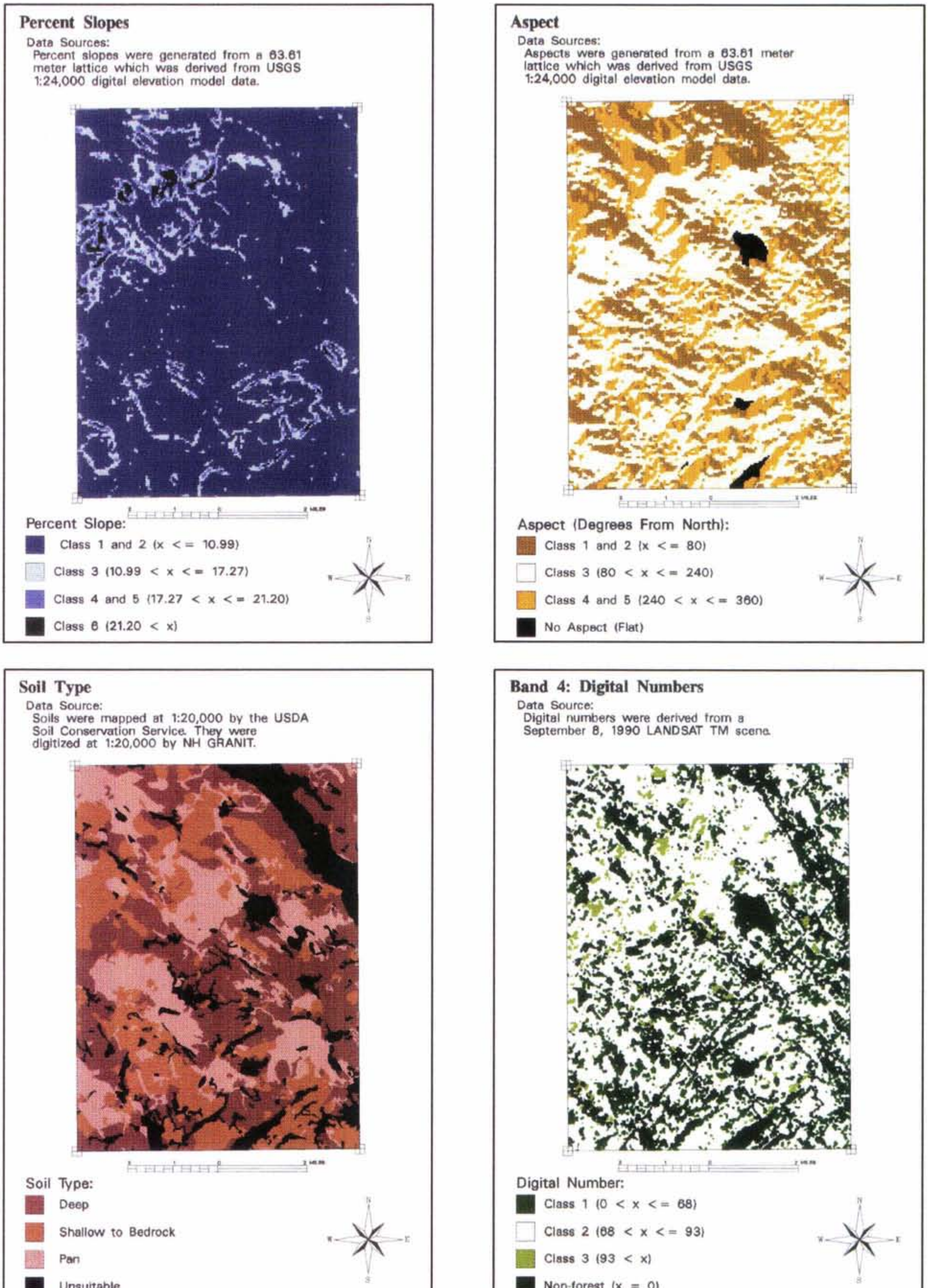

Plate 1. Habitat data for quadrangle 1.

Table 6. Chi-Square Analysis of General Habitat Characteristics at Orchid and Non-Orchid Sites.

Habitat Variables	% of forest	Observed # of sites	Expected # of sites	Chi-square	P-value
Soil Type				13.2	.001
deep	46.9	5	12.7		
shallow	18.4	6	5.0		
pan	34.7	16	9.4		
Slope Class				9.3	.010
1 and 2	54.1	8	14.6		
3	29.6	13	8.0		
4, 5, and 6	16.3	6	4.4		
DN Value				10.8	.004
1	51.00	8	14.8		
2	37.00	14	10.7		
3	12.00	7	3.5		
Aspect Class				.131	.937
1 and 2	23.5	7	6.3		
3	53.1	14	14.3		
4 and 5	23.5	6	6.3		

medeoloides sites than was expected. Digital values in Class 1 were less prevalent than expected.

The proportional importance of each habitat characteristic was calculated based on the chi-square statistic (Table 7). Highest potential habitat occurred where the sum of importance values was ten (with forest data) or seven (without forest data). High potential habitat occurred where combinations of significant characteristic values totaled seven or six

Table 7. Chi-Square Weight Modeling Scenario.

Slope		Soils		Forest	
Class	Value	Class	Value	Class	Value
1 or 2	−3	deep	−4	1	−3
3	3	shallow	0	2	3
4 or 5	0	pan	4	3	3
6	−3	other	−4	0	−3

Forest Data Available		Forest Data Unavailable	
Potential habitat	Total Score	Potential habitat	Total score
Highest potential habitat	10	Highest potential habitat	7
High potential habitat	7	High potential habitat	4
High potential habitat	6	High potential habitat	3

(with forest data) or four or three (without forest data). Highest and high potential habitat are displayed for Quadrangle 1 in Figure 2. The model identified 332 ha or 2.4 percent of the quadrangle as highest potential habitat, and 468 ha or 3.3 percent of the quadrangle as high potential habitat.

Nine of the 50 locations searched for *Isotria medeoloides*, or 18 percent, contained previously unknown sites for the orchid. Table 8 lists the predictions of each model for 23 *Isotria medeoloides* locations. For all the sites combined, when forest data were not utilized, the equal-weight model correctly predicted 13/23, or 57 percent, of the sites as potential habitat, and the chi-square model correctly predicted 18/23, or 78 percent, of the sites as potential habitat. The

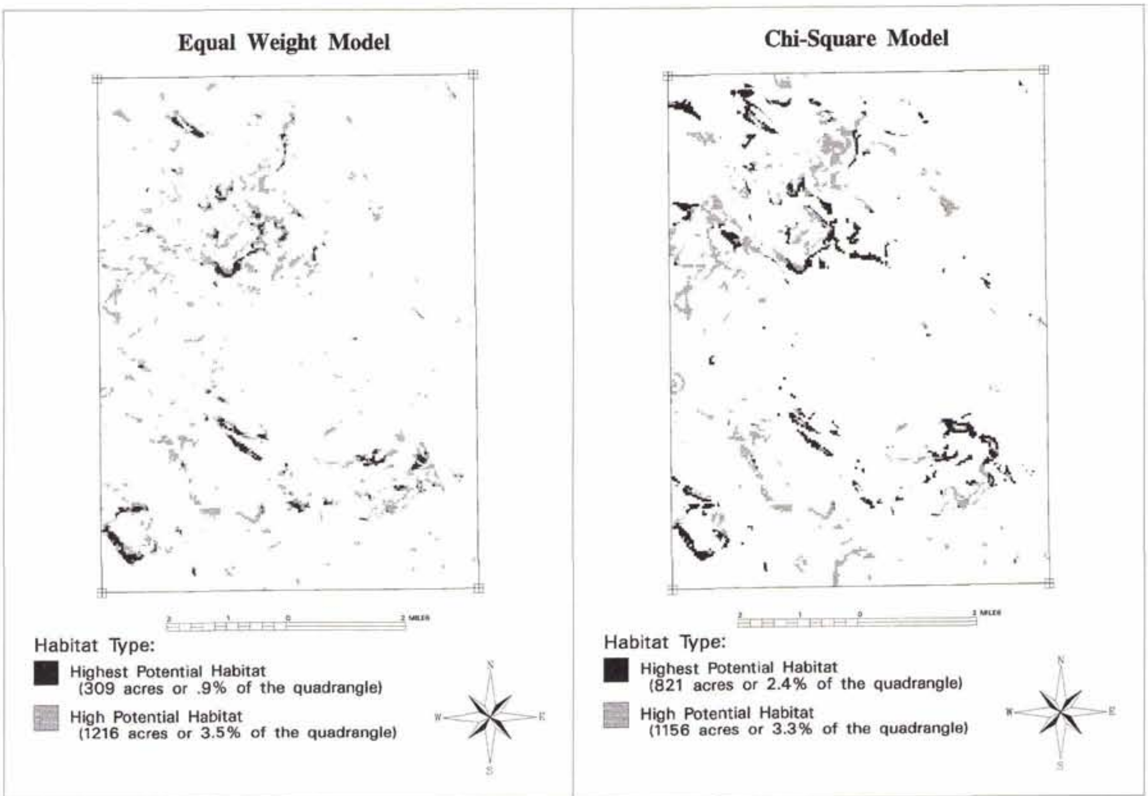

Figure 2. Habitat predicted for quadrangle 1.

TABLE 8. ASSESSMENT OF EQUAL WEIGHT AND CHI-SQUARE MODEL PREDICTIONS.

	Number of Existing Sites Predicted by Each Model			
	Equal Weight Model		Chi-Square Model	
Habitat Potential	sites in model development	sites not in model development	sites in model development	sites not in model development
Very Low	4	6	1	4
High	3	4	6	2
Highest	3	3	3	7
Accuracy	6/10 = 60%	7/13 = 54%	9/10 = 90%	9/13 = 69%
Total Accuracy	13/23 = 57%		18/23 = 78%	

equal-weight model predicted 6/10, or 60 percent, of the locations that were used in model development, and the chi-square model predicted 9/10, or 90 percent, of the locations that were used in model development. For the sites not included in model development, the equal-weight model predicted 7/13, or 54 percent, of the sites, and the chi-square model predicted 9/13, or 69 percent, of the sites.

The effect of including forest data in the models was assessed at ten sites. When forest data were included in model development, the equal-weight model correctly predicted 20 percent of the sites and the chi-square model correctly predicted 70 percent of the sites. When forest data were excluded from model development, the accuracy of the equal-weight model improved to 30 percent, and the accuracy of the chi-square model was unchanged.

Discussion

This work considered the feasibility of using general data layers in place of specific habitat information to predict potential habitat, and assessed the accuracy and limitations of two digital habitat models for *Isotria medeoloides*. Field measurements of ecological characteristics at *Isotria medeoloides* sites generated site-specific habitat information. Such large-scale, site-specific characteristics were unavailable in digital form, and could not be used in the GIS model. Instead, coarser habitat information at smaller scales (1:20,000 or 1:24,000) provided input to the models. Overlays of important habitat information identified areas of potential habitat for *Isotria medeoloides*. Evaluations of the models' predictions at known *Isotria medeoloides* sites assessed the models' accuracy and limitations.

The ecological characteristics measured at *Isotria medeoloides* sites were not directly used in the derivation of the *Isotria medeoloides* habitat models. However, information about ecological characteristics was important (1) to corroborate generalized habitat information at *Isotria medeoloides* sites, and (2) to help recognize preferred orchid habitat during subsequent field searches. The majority of sites contained a mix of trees characteristic of the transitional hardwood-white pine-hemlock forests (Westveld *et al.*, 1956). The structure and composition of the trees was similar to other New England mid-successional forests which have grown from abandoned fields. The sites were situated on a variety of aspects.

One-half of the sites were situated on pan soils, and the presence of an impervious layer in combination with gently sloped terrain appeared to exist at many locations. In these circumstances, water moves down slope above the pan and causes these soils to be seasonally wet (U.S. Department of Agriculture, 1977). This combination of characteristics may provide a suitable moisture regime for *Isotria medeoloides*.

GIS Data Layers

It was essential that habitat characteristics were measured at the appropriate scale for input to the GIS model. For each data layer, an average measurement technique was developed to correlate with existing digital data. The usefulness and reliability of the GIS model depended on the accuracy of each input layer. Specifically, errors in the agreement between map-based and digital measurements resulted in errors of omission and commission of potential habitat.

Field measures of percent slope at specific *Isotria medeoloides* locations were unsuitable for determining which range of digitally derived slopes were optimum for the orchid. The percent slope at site specific locations ranged from 0.87 percent to 12.28 percent; however, average percent slopes for each of the more broadly defined site areas ranged from 5.89 percent to 21.20 percent. Because many *Isotria medeoloides* sites were found at the base of slopes or on benches at mid-slope positions, the site-specific percent slopes were lower than the average slopes for the general area. The GIS required input of average slope measurements corresponding to the resolution of the DEM.

The most accurate method to model slopes characteristic of *Isotria medeoloides* sites would have been to measure slopes at orchid sites with the DEM. However, because digital coverage was unavailable for the entire study area, this approach was not possible. Instead, the grid method developed by Horton (1932) was used to measure average slopes.

The chi-square test between average slopes at *Isotria medeoloides* sites and average slopes at randomly distributed sites indicated a strong tendency for *Isotria medeoloides* sites to be associated with sloped terrain. Field evaluations also suggested that larger *Isotria medeoloides* populations had increased percent slopes (Sperduto, 1993). This information implied that moderate slopes were strongly associated with *Isotria medeoloides* habitat, and provided one useful indicator of potential habitat.

To accurately identify the range of average slopes associated with *Isotria medeoloides* sites in the GIS model, the map-based slope measurements must correspond to the digital slope measurements. Unfortunately, the KHAT agreement between map-based and digital slope measurements was 52.5 percent. Several factors may have limited the agreement. The grid sampling format of DEMs may poorly define detailed landform features in areas of otherwise low relief or in areas of complex terrain (Carter, 1988). Alternatively, the DEM slopes may be relatively accurate and the grid measure of slope (Horton, 1932) may be less reliable. The latter method is designed for use on watersheds which are normally much larger than *Isotria medeoloides* sites. At such a detailed scale, generalization of subtle landforms may occur. In addition, this map-based method is prone to less accurate measures because it is derived from a contour map which is itself a derived map product. In all likelihood, both the digital and map-based slope measures contained some degree of inaccuracy and contributed to their lack of correspondence.

The importance of aspect at *Isotria medeoloides* sites was minimal. A comparison of the average aspects at *Isotria medeoloides* sites and random sites had little chi-square significance. This suggested that sites with orchids occurred at particular aspect classes in the same proportion as these classes were present on the landscape. The distribution of 50 percent of the *Isotria medeoloides* sites at aspects between 80 and 240 degrees also implied that aspect was less important, because this range of aspects described nearly 50 percent of the possible aspects. Aspect had little value as an indicator of potential habitat in the GIS model.

The chi-square test showed that *Isotria medeoloides* sites occurred on pan soils with a greater frequency than was expected based on the frequency of these soils on the land-

scape. *Isotria medeoloides* may prefer the moist conditions associated with pan soils. The strength of this test depends, however, on the accurate mapping of the soil series. Because of the relatively large minimum mapping unit, inclusions of different soil types smaller than 1.6 ha, or in some cases up to 16 ha, were not differentiated. Therefore, small areas containing pan layers could be under-represented on the maps as compared to their true frequency on the landscape. If pan soils were more prevalent than indicated by the digital data, this would lower the significance of the chi-square test. *Isotria medeoloides* sites would occur on various soil types with a distribution more similar to the frequency of these soil types on the landscape. The validity of the chi-square test should increase as soil mapping is improved.

The overall agreement between field observations of impervious layers and the soil survey map delineations was approximately 50 percent. For pan layers, the agreement between field observations and NRCS delineations was higher. Because these measurements incorporated only 27 samples, they were not a robust test. Furthermore, the accuracy measures were not dependable because the number of samples in each category was not comparable. Despite these weaknesses, the test indicated that field observations and NRCS delineations differed at some *Isotria medeoloides* locations. Several of these differences resulted from the coarse nature of soil mapping in some forest areas.

The proportion of sites associated with pan layers was similar for field and map-based determinations. Therefore, it was considered legitimate to use map-based measurements to compare the percentage of *Isotria medeoloides* sites on pan soils to the occurrence of pan soils on the landscape. To strengthen the chi-square test, field determinations of impervious layers should be conducted at sites with and without orchids. Furthermore, assessment of a number of soil pits at both types of sites would provide more accurate results. The generalized nature of the data make it one of the least reliable data layers in the model.

Satellite data provided a forest component to the GIS model. The accuracy of the forest/non-forest classification was not quantified because this procedure is relatively straightforward to perform with successful results. However, errors of omission and commission in mapping forest habitat introduced error in the GIS model. The impact of this error was reduced because forest was the least limiting of the habitat layers (Plate 1). Acquisition of the satellite data occurred in 1990; therefore, some areas identified as potential habitat may have since been cut or disturbed.

The frequency of digital numbers greater than 68 for band 4 was greater at *Isotria medeoloides* sites than the distribution of these numbers at randomly selected forest locations, indicating that orchid sites were positively associated with high digital reflectance values. This test was limited to a smaller geographic area than the other chi-square tests, and for two sites it included 11 sub-population locations. Therefore, the test may have disproportionately emphasized the forest composition and structure of a few sites. The proportion of digital values in each class may have been more representative of all sites if satellite data had been available for the entire study area and more site locations had been included in the analysis. Alternatively, efforts to use image processing methods to classify the forest into different species assemblages, some of which are suitable for *Isotria medeoloides*, may have been more fruitful than analyzing the digital reflectances alone.

GIS Models of *Isotria medeoloides* Habitat

The GIS provided a framework to collect habitat information, to question the importance of each habitat characteristic, and to assess how best to combine characteristics. There were a multitude of potential ways to combine the data layers to predict potential *Isotria medeoloides* habitat. The GIS provided the capability to see the results of initial decisions, refine ideas, and evaluate changes to the model.

Two scenarios for predicting potential habitat for *Isotria medeoloides* have been presented. An understanding of the accuracy of each scenario was critical to determine the quality of each model. Recognition of the accuracy of each input data layer provided a basis for understanding the errors inherent in combination models. This section examines the overall accuracy of each model to predict potential habitat.

Field searches of potential habitat sites resulted in the discovery of previously unknown populations of *Isotria medeoloides* approximately 18 percent of the time. This percentage of success indicated that the GIS models were useful to assist in the identification of potential habitat for *Isotria medeoloides*. Considerable "negative search time" in very low potential areas that were traversed to reach predicted areas yielded no new occurrences of *Isotria medeoloides*. This finding supported the notion that *Isotria medeoloides* distribution was not random, and that sites identified by the models more often contained habitat suitable to *Isotria medeoloides* than sites not identified.

The percentage of sites found to sites surveyed was only an initial and approximate indication of the models' utility. This percentage was a very difficult number to determine for several reasons. First, it was difficult to define what constituted a site. To compare large and small predicted areas fairly, large sites had to be divided into multiple smaller sites comparable in size to small isolated sites. In addition, the time spent at each site had to be similar. Finally, to be absolutely sure that *Isotria medeoloides* was absent at a site would require diligent searching of nearly every square metre of the landscape. It is likely that a person could walk within 3 metres of a small population of plants and not realize that the plants were present. Such a high intensity of surveying was not performed in this study.

Characteristics of the life history of *Isotria medeoloides* also made the search record difficult to evaluate. Because plants may undergo dormant stages and remain subterranean for several years (Brumback and Fyler, 1988; Ware, 1991; Vitt, 1991), it was impossible to conclude that an area which appeared to be excellent habitat did not contain plants in a previous year. In addition, some sites may be able to support orchid populations, but due to unfavorable dispersal or other influences, the plants are not present. The logistical difficulties of determining what constituted a site visit, the impractical nature of covering every square metre of a site, and the biology of the orchid made the percentage of sites found relative to the number of sites surveyed a poor indication of the models' accuracy.

The percentage of known sites predicted by the models provided a much better indication of the models' accuracy. Due to the limited number of unused orchid sites available to evaluate accuracy (13 sites), ten sites which were included in model development were also evaluated. Without utilizing forest data, the equal-weight model correctly predicted 57 percent of 23 known *Isotria medeoloides* sites. Four of the ten sites which were included in the development of the model were incorrectly identified.

In the equal-weight model, potential habitat was narrowly defined because it required the co-occurrence of all or a majority of the habitat characteristics. Treating each habitat parameter equally was a poor assumption. The inclusion of less important features, such as aspect, excluded other areas that had appropriate characteristics for the more important habitat layers. Furthermore, if aspect or any other category received its lowest ranking at a site, the site was eliminated from potential habitat consideration.

The chi-square model provided a better combination of data layers to predict potential habitat. This model focused on locating combinations of habitat characteristics that were positively associated with known *Isotria medeoloides* sites. Without utilizing forest data, 78 percent of the model evaluation sites were correctly identified as potential habitat. Only one site used to develop the model was incorrectly predicted. This small site was atypical in that it had a low percent slope. The negative score this site received for slope precluded it from being considered as potential habitat.

The equal-weight model and the chi-square model provided two approaches to predict *Isotria medeoloides* habitat. Other ranking scenarios should be developed and evaluated to improve upon the current models. Logistic multiple regression or Bayesian classification techniques would have provided interesting, alternative models. However, the lack of continuous data throughout the large study area precluded the use of these approaches. As digital data become increasingly available, these more powerful statistical techniques may provide increased modeling capabilities.

Based on the limited number of sites on which the accuracy of the habitat models were evaluated, the chi-square model provided a fairly good indicator of potential habitat. As such, this model provides biologists with a tool to rapidly identify all potential *Isotria medeoloides* habitat within an area where digital data are available. This allows biologists to prioritize areas worthy of future field work for locating new occurrences of *Isotria medeoloides* and to rapidly assess potential habitat when conducting environmental reviews.

Despite the model's potential to assist biologists and resource managers, the limitations and constraints of the model must also be considered. First, the error inherent in the individual data layers must be recognized. Second, the error which resulted from the assumptions about the data layers' importance to *Isotria medeoloides* habitat, and thus how the data layers are weighted, should be continually assessed so that the model can be improved. Finally, and perhaps most importantly, the model should only be considered as a general indicator of potential habitat. The model was limited to only three small-scale ecological characteristics. Microsite factors may ultimately determine the suitability of an area for *Isotria medeoloides* habitat. Errors of both commission and omission of potential habitat occur, and therefore habitat maps generated from this model should not be considered as the final assessment on habitat quality for an area. It is recommended that biologists familiar with site specific characteristics of *Isotria medeoloides* sites perform field surveys of predicted habitat to determine the true potential of an area to support *Isotria medeoloides*.

Conclusions

This study utilized site-specific and general habitat information to identify ecological characteristics associated with *Isotria medeoloides* sites. Using generalized habitat data, chi-square tests between all *Isotria medeoloides* sites and randomly located sites assumed to be without orchids indicated that *Isotria medeoloides* sites were positively associated with moderately sloped terrain (11 to 17 percent), soils with a pan layer, and a digital reflectance greater than 68 for the NIR band (Band 4) of Landsat TM data.

The three significantly associated general landscape characteristics of slope, soil type, and forest reflectance were collected in digital form on a GIS and combined to create two predictive models: the equal-weight model and the chi-square model. The chi-square model, in which characteristics were weighted based on their chi-square statistic, was a better predictor of *Isotria medeoloides* habitat than the equal-weight model. The chi-square model correctly predicted 78 percent of 23 sites as high or highest potential habitat, while it eliminated 94 percent of the area in a representative quadrangle from consideration for potential habitat.

The accuracy of the model was limited, in part, by the accuracy of the input data layers. Digitally derived slope data had an overall agreement with topographic map-derived slope data of 60 percent. The true accuracy of the soil data is unknown; however, the large size of the minimum mapping unit (up to 16 ha in some cases) suggested that inclusions of various soil types occurred within mapped units. Forest reflectance values represented a small subset of *Isotria medeoloides* sites and may have overstated the reflectance characteristics of a few sites. The effect of input data layer inaccuracies was to generate errors of commission and omission of potential habitat in the overlay models. Therefore, it is recommended that field evaluations be used to determine the true potential of an area to provide habitat for *Isotria medeoloides*.

Despite some limitations, the GIS provided a useful tool for combining significant ecological habitat indicators to predict potential habitat for *Isotria medeoloides*. Due to the success of the model to locate new *Isotria medeoloides* populations, natural resource agencies such as the New Hampshire Natural Heritage Program have since used the model to prioritize field searches for additional *Isotria medeoloides* populations and to evaluate environmental reviews. In addition, as a result of the discovery of two *Isotria medeoloides* populations on the White Mountain National Forest, the USDA Forest Service has used a version of the model to help evaluate *Isotria medeoloides* habitat on the Forest. To date, no new populations of *Isotria medeoloides* have been discovered on the Forest. However, soil data in the Forest model are considerably coarser than those used in the original model, and this may be decreasing the accuracy of the output.

Future verification of the model and continued development of digital data layers should improve the current model and allow researchers to better predict *Isotria medeoloides* habitat. Furthermore, in combination with other digital threatened and endangered species data, the model may increase our ability to identify areas of significant biological diversity.

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