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Introduction

Prior to 1978, the known breeding distribution of Boreal Owls (*Aegolius funereus*) included much of the boreal forest zone of Canada, but did not extend south of the Canada–United States border. In 1978, however, a Boreal Owl nest was documented in northeast Minnesota (Eckert and Savaloja 1979). Subsequent to that discovery, the owl has been documented as a breeding species throughout the western Rocky Mountain states (Palmer and Ryder 1984, Holt and Ermatinger 1989, Hayward *et al.* 1993), and today is considered to be a regular nesting species in Minnesota (Lane 1997). The Boreal Owl is currently listed as a sensitive species in the Superior National Forest (SNF 1986) but is not listed by the Minnesota Department of Natural Resources as endangered, threatened or species of special concern.

As Minnesota's forests face increased logging pressures (Wolter and White 2002), it remains unclear if habitat changes due to forest management practices are related to the rarity of the Boreal Owl in northern Minnesota (Lane 1989, Wilson 1990, Lane 1990, Green 1995, Lane 1997). In Finland, Hakkarainen *et al.* (1997) found that moderate amounts of forest management (clearcuts) actually increased Boreal Owl reproductive success. In addition to preservation of suitable nesting sites, they suggested installation of artificial nest boxes to compensate for forestry-related loss of natural nesting habitat. At the moment, we are only beginning to understand what limits Boreal Owl abundance in Minnesota (Lane 1989, Lane and Andersen 1995).

To understand fully the reproductive success of Boreal Owls in Minnesota, we need to know more about the forest elements that they prefer; forest cover type and arrangement of types across the landscape is just a start. This paper examines the use of raw Landsat Thematic Mapper (TM) data on a band-by-band basis, coupled with Boreal Owl nest tree locations to examine potential links between satellite-measured forest reflectance and forest structural attributes as measured on the ground. If the leap to a satellite-based understanding of the habitat preference of Boreal Owls in Minnesota can be made, we will then be better equipped to make timely forest management decisions over large areas, which will be critical for the preservation of this unique forest predator in this region.

Background

In general, owls occur in many different habitats that support prey species (Craighead and Craighead 1956). Boreal Owls also live in a wide range of habitats throughout the boreal zone of the holarctic (Sonerud 1986, Korpimaki 1988, Hayward *et al.* 1993). North American populations of Boreal Owls appear to be more habitat specific than populations occurring elsewhere (Hayward *et al.*

1993, Lane *et al.* 1993, Wilson 1990). The requirements noted for North American populations may be a function of low population density. Conversely, European populations appear to be forced, by nature of their breeding success, to use suboptimal nesting habitats (Hayward *et al.* 1993). In Idaho, Hayward *et al.* (1993) concluded that Boreal Owl populations were not self-sustaining and relied largely on recruitment from larger Canadian source populations.

For populations found in North America, the question of what constitutes prime Boreal Owl breeding habitat is not clear. In Idaho, Hayward *et al.* (1993) studied forest vegetation structure at 33 Boreal Owl nest sites and 101 random sites. A large proportion of the sites where owls actually nested were characterized as having mature, uneven-aged (multistoried), spruce-fir cover types of higher basal area when compared to random sites. Furthermore, 21 vegetation structural variables including tree density, basal area, percent tree canopy cover by height, percent shrub canopy cover, and percent ground cover were analyzed for both nest and random sites. Six major vegetation structural components were identified. The first component described a gradient from older forest types with a high degree of structure and layering to younger forest types with little overall diversity. Successive components described discrete vegetation structural features such as dense cover 0–2 m above ground, heavy upper canopy cover and presence of large snags as being significant habitat variables. The fact that 21% of the singing and breeding sites were located in aspen dominated stands, the smallest cover type component in the study region (<1%), was noteworthy. Earlier, working in Ontario and Saskatchewan, Canada, Bondrup-Nielsen (1978) made similar observations concluding that Boreal Owls preferred older trembling aspen even though it was a minor forest component. Although these Idaho results shed much light on the habitats used by Boreal Owls in the northern Rocky Mountains, the authors advised against using their conclusions to make assumptions about populations elsewhere.

In Minnesota there appear to be two common variables associated with Boreal Owl territories: 1) large trees approaching pathological rotation (Lane and Andersen 1995), and 2) forest stand complexes made up of mixed hardwood and conifer (Wilson 1990). Lane and Andersen (1995) found that Boreal Owls prefer over-mature aspen ~85–90 years of age, adjacent to lowland stands of black spruce, as nesting sites. The proximity of lowland black spruce to nesting substrate apparently serves as roosting habitat (Lane 1997). Over-mature aspen (>40 years old) are important because they are susceptible to heartwood decay by the fungi *Phellinus tremulae*. Once infected, Pileated (*Dryocopus pileatus*) and other woodpeckers excavate the trees during their foraging and nesting activities. Boreal Owls then use the vacant cavities as nest substrate (Wilson 1990, Lane and Andersen 1995). Lane and Andersen (1995) also measured 20 habitat variables at plots centered around nest trees and plots randomly located in similar habitat and found significant variables included lower conifer basal area, larger cavity trees and shorter distances to other trees than on random plots. Other variables such as percent conifer cover, deciduous tree basal area and understory tree component were not found to be significant.

Digital satellite data have been shown to be a useful wildlife management tool for describing and/or quantifying avian habitat variables (Palmeirim 1988, Andries *et al.* 1994, Hunter *et al.* 1995, Hepinstall and Sader 1997). A popular source of these satellite data is the Thematic Mapper (TM) on board both Landsats 5 and 7, which provides spectral information about the earth's surface in seven bands or wavelength intervals: three visible, three reflective infrared and one thermal infrared. TM data are commonly classified into land use or cover type classes
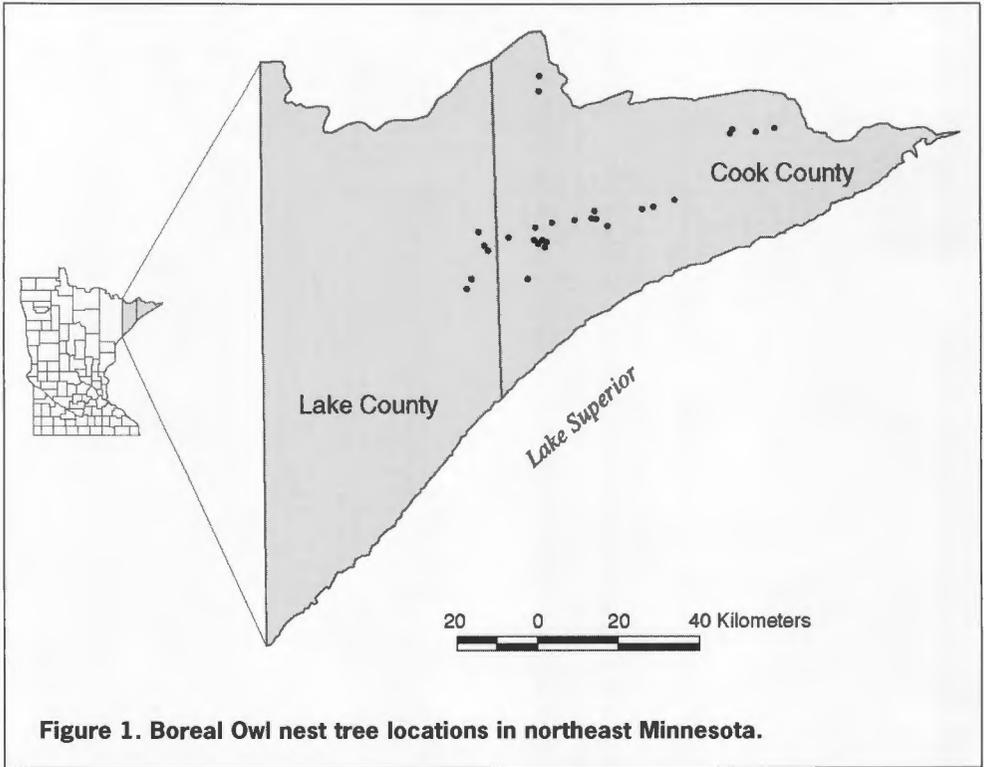
Figure 1. Boreal Owl nest tree locations in northeast Minnesota.

(Wolter *et al.* 1995). Ultimately, the digital land use or cover type maps produced are used as independent habitat variables for predicting whether some vertebrate species of interest is potentially present or absent from a particular landscape of interest (Andries *et al.* 1994, Hunter *et al.* 1995, Hepinstall and Sader 1997).

Use of satellite data in their raw-band form (reflectance or radiance) to describe avian habitats is rarely seen in scientific literature (Wallin *et al.* 1992, Hepinstall and Sader 1997). Potentially important forest structural information that may be inherent in raw satellite data are homogenized or completely lost when TM images are classified into vegetation cover types or land use classes. This may be problematic when trying to make predictions about avian habitat preference on a landscape scale — especially when it is not well known which habitat variables the bird species in question is responding to. Hayward *et al.* (1993) found that clas-

sification of forest cover type alone was insufficient in describing Boreal Owl nest site habitat. They found that key vegetation structural variables were not related to forest cover type. Furthermore, Hepinstall and Sader (1997) warn that habitat-class errors associated with a cover type map's arbitrarily defined classification scheme (e.g., pine, oak, aspen-birch, spruce-fir, lowland grass, etc.) will lead to errors in resulting predictive models regarding a wildlife species habitat preference.

Therefore, the focus of this research was the use of TM raw-band information and owl nesting data to determine if cover type reflectance surrounding Boreal Owl nest locations is significantly different from reflectance at random points in similar habitats. The null hypothesis was that raw TM reflectance information from nest-site locations could not be distinguished from TM reflectance at random locations within similar habitat. The

	TM1 (blue)	TM2 (green)	TM3 (red)	TM4 (NIR)	TM5 (SWIR)	TM6 (TIR)	TM7	NDVI	MSI
S^2_{owl}	3.37	1.43	1.28	139.76	40.15	5.54	2.34	19.89	11.45
S^2_{rand}	6.36	4.36	5.29	540.31	168.40	5.59	15.24	144.21	47.80
$mean_{owl}$	71.05	26.55	22.64	101.03	66.64	131.52	19.01	162.33	81.38
$mean_{rand}$	70.96	26.74	23.31	93.57	64.76	130.31	19.23	158.10	82.38
t-value	0.22	-0.67	**-2.26**	**2.46**	1.14	**2.52**	-0.47	**3.10**	-1.12

Table 1. Two tailed Student's T-test for significance (a = +/- 0.025) between TM spectral data from Boreal Owl nest tree locations and spectral data from random locations in similar habitat (df = 29). Significant T-values are in bold.

greater foliar surface area than needle-leaved species, they are generally much more near-infrared reflective than conifers. Near-infrared wavelengths are also sensitive to the status of leaf cellular structure (Tucker 1979). For example, healthy, green leaves are generally more near-infrared reflective than unhealthy, drought stricken or chlorotic leaves.

The NDVI (equation 1) is a ratio of near-infrared to visible red reflectance and is positively correlated to leaf area index, photosynthetically active radiation, photosynthetic capacity and several other important vegetation parameters (Tucker and Sellers 1986, Sellers 1987). Our NDVI results appear to be consistent with Lane and Anderson (1995). They found lower conifer basal area and higher tree density to be characteristic differences between nest sites and random sites. Consequently, broad-leaved tree species tend to have higher NDVI values than needle-leafed tree species due to the leaf area and cellular difference discussed above. Furthermore, densely spaced trees generally yield higher NDVI values than trees more sparsely arranged. With that said, since NDVI values were significantly higher at nest locations than the random location, it is possible that TM data are, indeed, detecting some of the forest composition differences that Lane and Anderson (1995) described. That is, forests with trees more densely arranged and/or with a greater hardwood component than random sites of similarly defined forest composition. Unfortunately, information regarding the overall age structure and subcanopy layer composition of forest trees surrounding Boreal Owl nest sites cannot be gleaned directly from these results without detailed habitat measurements on the ground.

Hayward *et al.* (1993) noted that Boreal Owls seem to preferentially select over-mature aspen as nesting substrate in Idaho. They also found the abundance of snags greater than 38 cm in diameter was significant in describing Boreal Owl habitat there. In Minnesota, Lane and Andersen (1995) found 92.3% of cavity trees used by Boreal Owls to be trembling aspens of advanced age; by 1997, this figure increased to 93.2% (Lane 1997).

We theorized that the MSI (equation 2) might be able to detect subtle differences in the number of snags or trees showing decreased vigor between nest and random sites. MSI was included as a variable in these tests because it has previously been used as an index to monitor the severity of forest decline (Vogelmann and Rock, 1988) and reduced canopy vigor (Vogelmann and Rock 1989) in the eastern United States. Shortwave infrared reflectance of vegetation is driven, in part, by the amount of moisture contained in leaf tissues. Drought stricken or dead leaves have higher shortwave infrared re-

alternative hypothesis states that raw TM data provide enough information on landscape variables to distinguish Boreal Owl nesting habitat from similar, random locations. A 2-way Student's T-test is used to test this hypothesis.

Data and Methods

Boreal Owl cavity tree locations (Figure 1) are from surveys conducted during the late winter/early spring breeding season in northeastern Minnesota between 1988 and 1992 (Lane and Andersen 1995). For a description of the study area, see Lane (1997) or Lane and Andersen (1995).

The imagery used was acquired by Landsat TM on 2 July 1988. Raw TM spectral variables consisted of the seven individual TM bands and two derived indices: the normalized difference vegetation index (NDVI) and moisture stress index (MSI), where TM3 is visible red (0.63-0.69 mm), TM4 is near-infrared (NIR, 0.76-0.90 mm) and TM5 is shortwave infrared (SWIR, 1.55-1.75 mm).

NDVI = [(TM4-TM3)/(TM4+TM3) +1] * 100 (1)
MSI = [(TM5-TM4)/(TM5+TM4) + 1] * 100 (2)

Copies of field maps and written descriptions of 30 Boreal Owl cavity tree locations were used to locate points within the satellite image. Once the points were located, reflectance information was extracted from the Landsat image and stored in a separate file. Since Boreal Owl nest cavities are largely located within intact forest stands of mixed conifer and hardwood composition in northeastern Minnesota (Wilson 1990, Lane and Andersen 1995, Lane 1997), a satellite-derived forest cover type classification (Wolter and White 2002) containing these general types was used to stratify the imagery prior to the selection of 120 random points.

A 2-way Student's T-test was used to determine whether there were significant spectral differences between Boreal Owl nest cavity locations and stratified random locations.

Results

Of the seven raw-band variables tested, three were statistically significant (Table 1). TM band 3 (visible red) was the only visible band to show a significant difference (negative) from stratified random visible reflectance data. Conversely, the near-infrared (TM band 4) reflectance of areas around cavity tree locations exhibited nearly equal but opposite significance (positive) from reflectance around randomly located sites. Also, a positive significant difference was detected between nest sites and stratified random sites using TM band 6 (TIR, 10.4-12.5 mm) thermal data (Table 1), which is sensitive to landscape surface temperature differences.

Of the two indices tested (equations 1 and 2), NDVI data from Boreal Owl cavity tree locations showed a strong positive significant difference from random site, NDVI data. This index is a ratio of near-infrared to visible red reflectance and is positively correlated to leaf area index, photosynthetically active radiation, photosynthetic capacity and several other important vegetation parameters (Tucker and Sellers 1986, Sellers 1987). Lastly, MSI values from the nest locations were not significantly different from random location MSI values.

Discussion

Lower visible red reflectance at nest sites (Table 1) may be suggestive of more densely arranged vigorous trees than trees at random sites. Visible red electromagnetic energy is known to inversely correspond to the amount of chlorophyll in plant leaf tissue (Tucker 1979). As chlorophyll density increases, greater quantities of visible red radiation are absorbed, leaving less to be reflected back into the atmosphere.

The greater near-infrared reflectance detected at nest site locations (Table 1) may be indicative of a reduced conifer component in the forests around nesting areas. Because broad-leaf tree species have an extra layer of cells — palisade mesophyl l— on their top surface and far

flectance than normally hydrated, healthy leaves. As a result, the normalized ratio of shortwave infrared to near-infrared reflectance (equation 2) is higher for stressed and dying leaves than for healthy leaves. Ultimately, MSI information was not found to be a significant variable.

Perhaps the lack of significance between nest site MSI values and random MSI values is ecologically characteristic of Minnesota Boreal Owl habitat. Lane and Andersen (1995) concluded in their Boreal Owl management recommendations for the Superior National Forest that snag retention, as a silvicultural practice, was not necessary in Minnesota but provided no data to substantiate this recommendation.

The most unusual, and unpredicted, result was the significance of the thermal band (TIR) in characterizing Boreal Owl nest locations. In this study, the forest around nest locations was found to be slightly warmer than random sites (Table 1). Although these satellite data were not from the Boreal Owl breeding season in Minnesota, it remains encouraging that TM data may be capable of detecting this potentially important habitat difference. In Idaho, Boreal Owls appear to roost in vegetation that minimizes heat stress when ambient temperatures exceed 4° C (Hayward et al. 1993). Hayward et al. (1993) observed that Boreal Owls exhibited physical signs of heat stress (gular fluttering) when temperatures were as mild as 18–23° C. In Minnesota, Boreal Owls roost in lowland black spruce stands near nest locations (Lane and Andersen 1995), which are cooler during the warm days of spring than more mesic sites (personal observation). Landsat thermal data could be a useful, additional tool for understanding Boreal Owl habitat preference throughout northern Minnesota.

Suggestions for Future Work

The next phase of this research should be aimed at repeating these procedures using TM data acquired during the vocalization and nesting period from 15 March – 15 April. These TM data might allow a look through the top of the forest canopy at potentially significant forest structural variables below. It would also be interesting to see whether TM thermal data could be used to discriminate between nest sites, randomly located sites in similar habitat and the roosting habitats used by Boreal Owls in northern Minnesota within this time frame.

Furthermore, a spatial component to the analysis should be incorporated. Hayward et al. (1993) found that Boreal Owls rarely roosted within 500 meters of the nest tree and most of the roosts were greater than 1000 meters away. Lane and Andersen (1995) found that lowland black spruce stands near Boreal Owl nest sites are the preferred roosting and foraging habitat of nesting males. The authors speculate that size of the nesting home range might reflect limited resources. In northeastern Minnesota, black spruce lowlands are not a scarce resource, although suitable nesting habitat adjacent to these lowlands may be. Also, proximity of suitable nest trees to larger, predatory owl nests may affect breeding success of Boreal Owls (Hakkarainen and Korpimaki 1996). Therefore, step-wise buffering procedures performed on raw and classified TM data, with nesting/singing locations as focal points, may shed light on what defines Boreal Owl abundance in Minnesota.

Conclusions

Nest trees of 30 singing male Boreal Owls were located by Lane and Andersen (1995) during the late winter/early spring breeding seasons in northeast Minnesota from 1988 to 1992. Raw Landsat TM reflectance information from 2 July 1988 were extracted for each of these locations. These satellite data consisted of the seven raw TM bands, normalized difference vegetation index (NDVI) and the moisture stress index (MSI). TM data from 120 stratified, random locations were also selected for comparison. Of the nine spectral variables, TM3, TM4, TM6

and NDVI data from the nest locations were statistically distinguishable from the stratified, random TM information. Boreal Owl nest sites were distinguished from random locations by having higher near-infrared, higher NDVI, lower red and higher thermal infrared spectra. These spectral signatures are suggestive of Boreal Owl nest sites being slightly warmer, possibly with greater hardwood composition and/or having greater tree density than sites randomly located in similar habitat. However, to be more useful as a landscape scale predictive tool, field measurements of Boreal Owl nest areas, during the breeding season, must be made to validate the satellite reflectance information. Empirically, though, TM data does appear to contain significant spectral information about the physical nest site characteristics of the Boreal Owl in Minnesota.

Whether Boreal Owls prefer over-mature trees directly or whether they are drawn to structural attributes inherent to older forest ecosystems is unknown. Hayward *et al.* (1993) theorized that Boreal Owls could perhaps be focusing on old growth forest ecosystems because owls inherently associate these communities with greater abundance of nest substrates.

Using these simple techniques, it is evident that certain information contained in raw TM data may be characteristic of Boreal Owl nest locations in Minnesota. Therefore, the alternative hypothesis of this research must be adopted. To this end, satellite remote sensing may be useful to investigators as a first-pass template for highlighting those habitats that are spectrally most similar to known nesting locations. Future research should be focused toward analyzing TM data collected during the breeding season. These data will afford a better look at subcanopy vegetation structure indicative of Boreal Owl nesting sites. In addition, a spatial component should be incorporated into the analysis of TM data. This would be done for the purpose of inves-

tigating the spatial relationships between roosting, foraging and nesting habitat. The results of these analyses may be invaluable for characterizing Boreal Owl habitat requirements on public and private lands in northeastern Minnesota.

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