Article

Improving Eastern Bluebird nest box performance using computer analysis of satellite images

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Abstract
Bird conservationists have been introducing man-made boxes in an effort to increase the bluebird population. In this study we use computer analysis of satellite images to show that the performance of the boxes used by Eastern Bluebirds (*Sialia sialis*) in Michigan can be improved by ~48%. The analysis is based on a strong correlation found between the edge directionality measured in the satellite image of the area around the box, and the preferences of the birds when selecting their nesting site. The method is based on satellite images taken from Google Earth, and can be used by conservationists to select a box placement strategy that will optimize the efficacy of the boxes deployed in a given area.

Keywords Bluebird; satellite images; image analysis; nesting boxes.

1 Introduction

There are three major species of bluebirds consisting of the Eastern Bluebird (*Sialia sialis*), the western bluebird (*Sialia mexicana*) and the mountain bluebird (*Sialia currucoides*), which all reside across the United States and in various parts of North America (Davis and Roca, 1995). The group that lives in Michigan is the Eastern Bluebirds, which are cavity nesters and part of the thrush family (Davis and Roca, 1995). The Eastern Bluebird’s numbers have drastically declined since 1938 until the 1970s due to many factors (Stokes and Stokes, 1991). These include, in addition to the increased use of pesticides and harsh weather, the devastation of nesting areas from urban sprawl in conjunction with the competition introduced by non-native species (Sauer and Droege, 1990; Stokes and Stokes, 1991). The starling (*Sturnus vulgaris*) that was introduced to North America in 1890 has not made as much of an impact on the species as originally thought, but the house sparrow (*Passer domesticus*) released in 1950 is the species that contends most with the bluebird for nesting locations (Stokes and Stokes, 1991; Pogue and Schinell, 1994; Koenig, 2003).

As a result of the severe deterioration of the population, individuals and non-profit groups have been working diligently to prevent extinction. Thomas Musselman was the first to begin efforts of conservation in 1934 with the introduction of nesting sites for bluebirds along roadsides (Stokes and Stokes, 1991). Since then, others have followed with their own methods of preservation. Education is one of the techniques used in conservation.

Cornell University Lab of Ornithology provides a public database that contains all records collected by individuals participating in the program (Bonney et al., 2009), allowing others to learn and take part in the process thereby educating and establishing an interest (Brossard et al., 2005). Oakland County Parks and

Recreation participates in this effort by integrating bluebird nest boxes at some of their parks. Volunteers are enlisted to monitor and record their progress once or twice a week throughout the nesting season. Once the data are collected, they are sent to the Cornell University Lab of Ornithology to be added to their NestWatch Project.

The purpose of installing and monitoring the bluebird nest box is to facilitate population growth (Hsu and Humpert, 1988). To successfully accomplish this task, it is important to understand what makes the Eastern Bluebird choose one nesting location over another. As natural cavities have diminished, man-made boxes have been introduced to help with the decline. The size of the artificial box does not significantly influence usage, but when open top designs are employed they are found to be successful (Pitts, 1988; Radunzel et al., 1997). Nest maintenance is also important to keep them clean, and free from competitors such as mice (Hsu and Humpert, 1988). They prefer to reuse old nests left intact as long as they do not contain harmful parasites (Davis et al., 1994). This could be due to the fact that bluebirds favor nesting locations they have found productive in the past (Pinkowski, 1979).

The boxes should be strategically placed for optimal use (Willner et.al, 1983). Bluebirds prefer habitat consisting of large grassy areas that have a few trees or posts for perching nearby (Davis and Roca, 1995). They use the perches for hunting and foraging in the location around the nest (Pinkowski, 1977; Davis and Roca, 1995). Although natural habitats produce the best result for bluebird reproduction, golf courses can be successful locations as well, even more so than other artificial areas (LeClerc et al., 2005; Stanback and Seifert, 2005; Cornell et al., 2011). Furthermore, the boxes should be placed approximately 30 meters from the forest's edge to prevent Wrens from occupying them (Rendell and Robertson, 1990; Stokes and Stokes, 1991). Additionally, bluebirds prefer boxes that are placed in pairs (Plissner and Gowaty, 1995). Ideally, a swallow will take up residence in one while a bluebird will inhabit the other, which results in a mutually beneficial relationship (Stokes and Stokes, 1991).

Understanding how and why a bluebird selects its nesting location is important for increasing box usage and population. Birds have very distinguished eyesight which enables them to visualize their surroundings with greater detail than that of a human, and vision is commonly considered the bird's most dominant sense (Moss 2007). This is demonstrated by the bluebird's hunting technique of surveying the field for prey (Davis and Roca, 1995), and the use of colors to distinguish between a juvenile and an adult (Ligon and Hill, 2009).

Here we studied preferences and performance of the nesting boxes using satellite images of nesting locations in conjunction with the nesting statistics. The method is based on computer analysis of the edge directionality in a satellite image of the area around the box, and can be used to assess the future performance of the box before it is placed in the field.

2 Methods

The experiment is based on the nesting boxes placed for the Cornell Lab of Ornithology NestWatch project by Oakland County Parks and Recreation in Michigan, who contributed their data for the 2010 nesting season, providing the breeding figures as well as the geographic latitude and longitude for all 124 boxes. Satellite images for each pair of boxes were gathered from Google Earth by entering the exact longitude and latitude coordinates, producing images of the areas around these boxes. All images were acquired during the summer, so that the satellite images reflect that area around the box at the time the birds select nesting sites. The "Earth" feature was selected without the Google-added digital labels to avoid including non-natural features in the image. The images were taken at the 20 meter level zoom feature and saved in the Tagged Image File Format (TIFF). After all images were collected, 694x399 pixel regions were cropped from the center of the image so that all processed images were of the same size, as demonstrated by Figs. 1 and 2.

Using the Wndchrm image analysis method (Shamir et al., 2008), a large set of 2873 numerical image content descriptors was computed such that each image was divided into 16 equal-sized tiles to magnify the signal of the content descriptors (Shamir et al., 2010). Each image content descriptors numerically reflects the visual content of the image, as thoroughly explained in (Shamir et al., 2010).

The images were then analyzed using a method for finding correlation between visual content and numerical values (Shamir, 2011) to determine whether there was a correlation between the images and the nest box data. Since bluebirds use one of the boxes in each pair of neighboring boxes, normally at least one will have no nesting attempts, and therefore data from the box with the maximum number of nesting attempts in each pair were used for analysis. The experiment was repeated such that 75% of the samples (93 images) were used for training the system (allowing the computer to automatically characterize the differences between used and unused boxes), and the remaining 31 images were used for testing whether the computer can predict if a box was used or not. To obtain statistically significant results, the experiment was repeated 100 times such that in each run different images were allocated for training and test sets, and the deduced Pearson correlations were averaged across the runs (Shamir, 2011).

An important numerical image content descriptor that was tested was the edge directionality, which numerically reflects the distribution of the directions of the edges detected in the image. An edge is a sharp change in the brightness between neighboring parts of the image. In image processing, each pixel in an image has its measured edge magnitude, which represents the difference in the brightness between the pixel and its neighboring pixels, and its edge directionality, which reflects the direction of the brightness differences. In this study the directionality is computed using the standard Prewitt gradient (Prewitt, 1970). The edge directionality is determined by first applying the basic Prewitt image convolution such that the original image *I* is convolved horizontally at pixel *(x,y)* using the convolution matrix *Gx*, and vertically using the convolution matrix *Gy*, where

$$Gx = \begin{bmatrix} -1 & 0 & +1 \\ -1 & 0 & +1 \\ -1 & 0 & +1 \end{bmatrix}, \quad Gy = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ +1 & +1 & +1 \end{bmatrix}.$$

The directionality of each pixel *(x,y)* is determined by $atan(|Gy \cdot I_{x,y}|/|Gx \cdot I_{x,y}|)$, such that $I_{x,y}$ is the 3x3 window in the original image *I* centered around the pixel *(x,y)*. The directionality values are computed for all pixels in the image and deconvolved into an 8-bin histogram. This simple method for edge directionality analysis can measure the images in a quantitative fashion that is highly difficult to detect and measure by manually observing the image (Shamir et al., 2010).

Recent studies have shown that edge detection has significant effect on the human ability to interpret natural scenes (Neri, 2011). In natural images many of the edges cannot be easily noticed since the human vision is not sensitive to subtle differences in gray levels, and in fact the human eye can only sense 15 to 25 different levels of gray. However, the computer analysis used in this experiment is sensitive to 256 gray levels, and can accurately measure the edge directionality and detect subtle differences between edge directionality in different images (Shamir et al., 2008; Shamir et al., 2011). For example, Table 1 shows the edge directionality histogram for Figs. 1 and 2.

All source codes and software used in the experiment are publicly available and can be freely downloaded at http://vfacstaff.ltu.edu/lshamir/downloads/ImageClassifier.

Table 1 Edge directionality histogram for Figures 1 and 2.

Figure	Bin 0	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7
1	8337	8337	9351.75	9351.75	9351.75	9351.75	9351.75	9351.75
2	8539.25	8539.25	8539.25	8539.25	8539.25	8539.25	8539.25	8539.25

Table 2 Pearson Correlation between the different bins in the Edge Direction Histogram and the number of nesting attempts

Bin 0	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7
-0.17551	0.292811	0.207257	-0.39621	-0.14002	0.335591	0.319851	-0.33837

Table 3 Percent of nesting predictions for each edge direction histogram bin

	Bin 0	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7
Prediction	0.6504065	0.67886179	0.66666667	0.73577236	0.63821138	0.70731707	0.71138211	0.67479675

Fig. 1 Google Earth satellite image of box number OO 43.

Fig. 2 Google Earth satellite image of box number OO 19.

3 Results

Our results show that there was a correlation between bluebird nesting attempts and the visual content of the 20-meter satellite images. The Pearson correlation between the image content and the nesting attempts was 0.496 (P<0.001), which shows that Eastern Bluebirds are sensitive to the landscape around the box when making their site selection decision, and that the visual information that they use is contained in the Google Earth images. The numerical image content descriptors that had the strongest correlation with the nesting attempts were the edge directionality features, and the correlation values of the different bins of the histogram are listed in Table 2.

Additionally, the bins of the edge directionality histogram can be used to predict whether a given box will be used by bluebirds. This was done by first averaging the values of used and unused boxes for each bin in the histogram for finding threshold over which the box is predicted to be used by bluebirds for nesting. Table 3 shows the prediction power of each bin. As can be learned from the table, while all bins are roughly similar by their prediction power, bin 3 provides the strongest predictive signal, and can predict with accuracy of ~74% whether a given box will be used for nesting. That is an improvement of ~48% compared to selection of the boxes in a fashion that is not sensitive to the satellite image of the areas around them, as done by Oakland County Park's current box placement strategy.

4 Conclusion

In this study we found that the edge directionality measured in satellite images can be used to predict the efficacy of bluebird nest box placement. The results suggest that bluebirds use a certain visual pattern found in the landscape around the boxes to determine whether to use the sites for nesting or not. This corresponds with the physiology of birds indicating they are visual and their sight is acute (Moss, 2007). In addition to selecting the proper habitat, placing boxes the appropriate distance apart to avoid territorial disturbances, and grouping them into pairs, analyzing the directional representation of the surrounding landscape could lead to increased occupancy.

A practical application could be developed to aid conservationists in their effort to increase the Eastern Bluebird population. Using satellite images of areas to determine the edge direction histogram may present information as to the placement that could produce optimal habitation. Provided the image is the same size as the analyzed image, the developed application could determine if a box placed in the position would be used or not due to a better than random prediction. Future work will aim at the implementation of this method to the NestWatch project to find the most effective locations for box placement in terms of potential bluebird nesting.

Additionally, the results from this experiment can be extrapolated and tested for other species to determine if the correspondence between edge directionality and preferred nesting areas is a consideration for species other then Eastern Bluebirds. The implementation of the analysis of the edge directionality is part of the open source Wndchrm image analysis software package (Shamir et al., 2008).

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