SOUTHERN ILLINOIS UNIVERSITY
EDWARDSVILLE

September 30, 2008

Len Meier, Chief
Program & Technology Support Branch
Office of Surface Mining
Department of Interior
Alton Federal Building
510 Belle Street
Alton, IL 62002

Re Final Report for Indiana Bat Pilot Study (# S07AC12434)

Dear Len,

Please find enclosed a copy of the final report for our project entitled: **Evaluating Indiana Bat Habitat Conditions on Surface Coal Mine Sites Using Remote Sensing Technologies: Pilot Study**. The narrative contains the study's goals & objectives, background information, methods, results and our analysis and conclusions. We have also included numerous figures (images) that show the primary points for our assessment and conclusions.

Please let us know if there are any questions.

Thanks again for the opportunity to be involved with this project and we would very much be interested in continuing with it (as we describe in our recommendations).

Sincerely,

Michael J Starr
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Evaluating Indiana Bat Habitat Conditions on Surface Coal Mine Sites Using Remote Sensing Technologies: Pilot Study

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September 30, 2008

Project Description

1.0 Objectives

The ultimate goal of this project is to develop a suitability index, using remote sensing technologies, to both inventory and evaluate, patch and landscape habitat features suitable for the Indiana bat on or near reclaimed Indiana mine sites. The criteria used for this index will be based on documented research which identifies the critical elements of foraging habitat and roosting sites for the Indiana bat. Some of the elements that may be included in this suitability index include forest structural characteristics, tree conditions, species and snag composition, canopy cover, solar exposure, land uses, topography, and their spatial relationships. Remotely sensed images (from satellites or aircraft) will be acquired and interpreted in an attempt to determine which elements exist and which are needed to improve habitat suitability on reclaimed mine sites.

To gain a better understanding of key summer habitat characteristics, known Indiana bat maternity colonies near reclaimed mines will be analyzed in this pilot study. These locations represent areas where surveys confirmed the presence of Indiana bats within the study area. Information from these sites will be used as a control in the future, to evaluate local conditions on current or reclaimed mine sites. In addition, because of the extensive geographic range and varying environmental conditions utilized by the species, landscape level information will be needed to identify the full extent of critical habitat elements and habitat preferences of the Indiana bat. Given the eventual scope necessary to fully assess this species habitat, remote sensing technology may offer the best and most efficient method of study. To the best of our knowledge, few studies have been validated which assessed habitat conditions at more than a site specific level.

Remotely sensed imagery, in addition to its large geographic coverage, also can provide high temporal frequency, and thereby can provide new ways to reveal and assess conditions required by the Indiana bat. Information gaps currently exist which limits our understanding of the basic habitat requirements of the species on both the local and regional level. The development of a remote sensing protocol, based on known habitat conditions and documented research of habitat needs, will improve efforts to analyze the effectiveness of forest reclamation. The specific objectives of this pilot study include:

(1) Obtain imagery from a variety of remote sensing sources and technologies for the study area and from known Indiana bat summer habitat in coal mining areas.

(2) Test the utility of these remote sensing technologies to inventory and assess the quality of actual and potential Indiana bat summer habitat and monitoring protocol.

(3) Develop a method to better analyze summer habitat quality of the Indiana bat, which in turn, will eventually result in a "suitability index".

Results from this phase of the proposed study will help refine the long term goals of this project. But in general, it will also help increase our understanding regarding which environmental elements, that are considered important for Indiana bat habitat, can be identified from various types of imagery. This in turn will enable improved recommendations for the mine permitting process and general habitat assessment strategies after mining operations have ceased.

2.0 Background

Indiana Bat (*Myotis sodalis*) Decline & Summer Habitat Characteristics

The Indiana bat is a small (7-10 g) insectivorous animal with a range that includes portions of more than 20 states in the northern mid-west and northeastern regions of the U.S. However, due to large population declines and the loss of suitable winter habitat, nearly 90% of the bat population ended up hibernating in three or four caves (McNab 1980). As a consequence of these factors, the Indiana bat was among the first species to receive formal listing as an endangered species (in 1967) by the United States government. At this time, the estimated population was 750,000 and the focus for the recovery plan was on the protection of suitable winter habitat sites (hibernacula). However, based on a surveys conducted by the U.S. Fish and Wildlife Service (FWS) between 1995 and 1997, the current Indiana bat population is estimated to be only 350,000, showing a 50% population decrease since the 1960's (FWS, 1996), in spite of the earlier efforts to protect winter habitat (Menzel et al., 2001).

While this overall rate of decline has not been consistent throughout their range, the continued general population decline in spite of the protection of their hibernacula, suggests that there are also problems in the spring and summer roosting and foraging habitats, where females gather in maternity colonies (Kurta & Whitaker 1996). As a result, many of the more recent studies have focused on female Indiana bat summer foraging areas, behaviors and diets.

This new research has shown that the Indiana bats are feeding generalists, utilizing more than 10 orders of arthropods. In addition, they are opportunistic in that they change which types of insects they focus upon both regionally and seasonally, based apparently on prey availability (Kurta & Whitaker 1996; Tuttle et al. 2006). However, they seem to forage primarily in and around forest habitat, often within edges created by agricultural fields and grasslands, though the type of woodland is quite variable from uplands to floodplain forests (Kurta & Whitaker 1996; Sparks et al. 2004; Tuttle et al. 2006;). In addition, they tend to avoid foraging in developed areas, even when the land is maintained to support their preferred species (Sparks et al 2004).

Further analysis of landscape level characteristics (macrohabitat) again shows the bats to be generalists, inhabiting areas with land cover values ranging from 20-80% agriculture **or** forest canopy (Kurta 2004). One key element seems to be some level of patchiness, as they prefer to forage along woodland edges and within corridors (Carter et al. 2002; Kurta 2004), but the degree of patchiness is unclear. The only macrohabitat feature that has been shown to be significant in determining the quality of summer habitat for the IB is the density of snags (for current roost sites) and large tree density for current and future roost sites (Farmer et al. 2002; Miller et al. 2002).

At the local level (microhabitat), summer roosting sites again appear to be the key element in habitat quality for the Indiana bat. For example, in spite of the fact that they have been found to utilize more than 30 tree species, they have been found to use only 5 species more than 85% of the time (Kurta 2004). In addition, they seem to prefer snags that are relatively large, at least 20 m tall, 45 cm dbh, with remaining hard bark covering at least 50% of the trunk surface (Menzel et.al, 2001). However, they will only utilize a specific snag for 2-3 days, moving to another within about 5 km of the last one (Kurta 2004). Therefore the number (per acre or ha) and type of snags appears to be a very important element in the quality of the habitat. Finally, the location (in addition to the height) of the snags appears to be important. Primary roosts were most often found to be on edges or in gaps of the forest, due in part to the apparent preference for a high level of solar exposure to help keep the roost warm (Carter 2004; Kurta 2004). This level of exposure can also be obtained in forest with high levels of canopy closure (up to 90%), if the roost tree is taller than the surrounding trees (Kurta 2004).

Therefore, though our analysis and comparison of various types of remotely sensed imagery will include many characteristics of IB summer habitat, we will focus on snags (potential, actual numbers, and location) and the overall patchiness of the surrounding landscape.

3.0 Study Area

The general area of interest for the later phases of this study includes potential Indiana bat summer roosting habitat located within the coalfields region of southwestern Indiana. Prior to human development, this area was dominated by grassland prairies and oak-hickory forests. Topographically, the area was made up primarily of lowland plains, broken up by rolling hills and low ridges, encompassing much of what is today the White River basin. Currently, the primary land use is agriculture, but the area also includes a high density of coal mines. Surrounding these areas are large tracts of forested areas, fragmented by numerous streams and ponds. Within this general study area, our pilot study focused on three areas with previously identified Indiana bat summer roost trees. This was necessary in order for us to develop our index from imagery of areas with known use by the Indiana bats. (Our conclusions here will be tested later on sites both with and without known IB use.) Two of the study sites encompass approximately 4 square miles (10.3 sq km) each. The first site is located in southwestern Davies County, along Veale Creek and the other is located along the eastern border of Gibson County and the western border of Pike County (where Hurricane Creek and Robinson Creek flow into the Patoka River). The final study area encompasses approximately 13.2 square miles (34.2 sq km) and is located in the western half of Warrick County along Pigeon Creek.
(See Figure 1 below.)

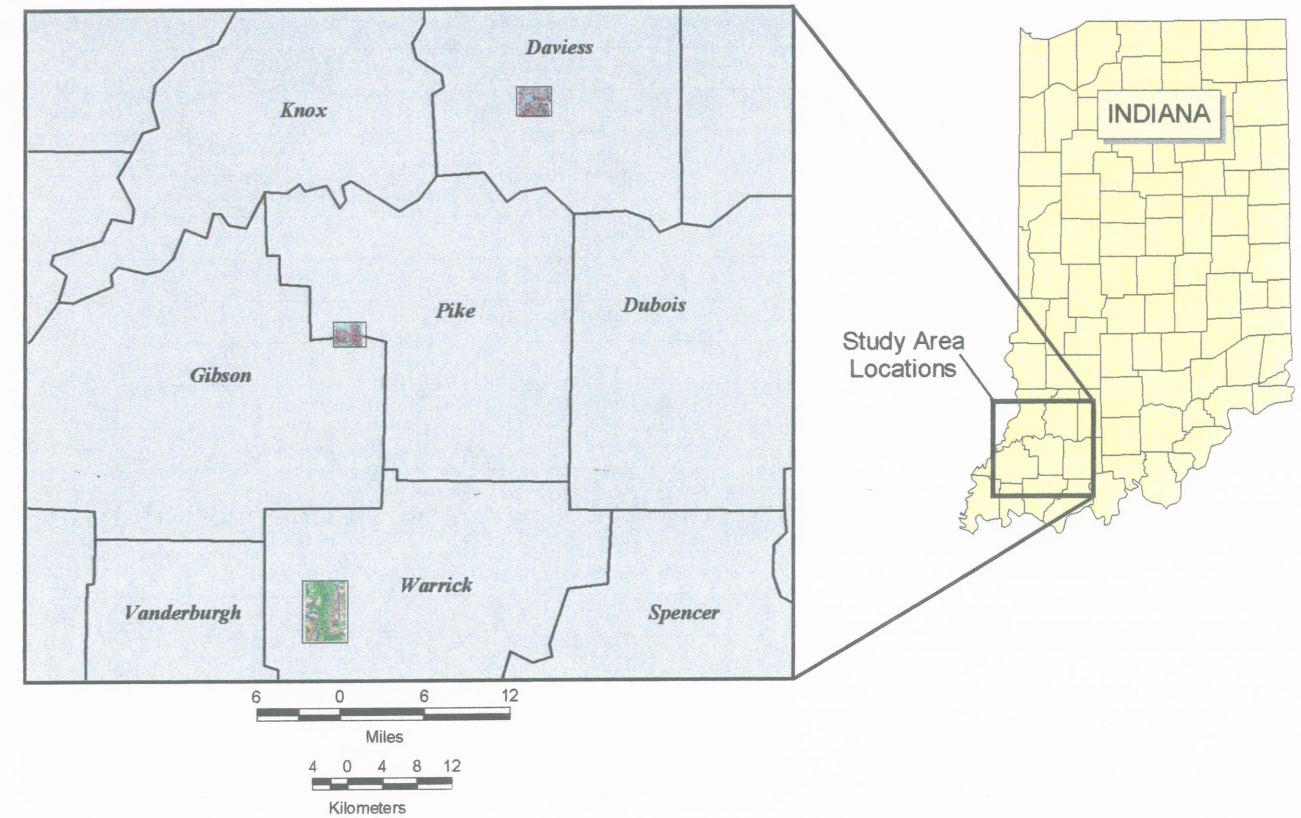


Figure 1
Map Showing Three Study Areas

4.0 Methods

Our overall methodological goal was to analyze a variety of readily available remotely sensed imagery, to determine the type and quality of land cover characteristics that each could provide. The focus was on the characteristics that could be used to predict potential Indiana bat summer habitat. For the first step of our landscape level analysis, we acquired three Landsat Thematic Mapper (LSTM) satellite images, one for each study area. We initially used Image Processing software (ERDAS Imagine 9.1) to conduct a landscape classification of the study area, focusing on the general types of land cover and their relative percentages for each study area. We also conducted visual surveys of the imagery to see if we could determine such characteristics as patchiness, forest cover and structure, etc., in an attempt to identify areas with the highest potential for IB summer habitat.

For the second step of our landscape level analysis, we used QuickBird (QB) imagery (supplied by OSM for site number 3 in Warrick County). These images are also from a satellite, but since they have a higher spatial and radiometric resolution, we conducted the same analyses to determine if this imagery could provide a more accurate land cover classification. In addition, we again conducted a visual analysis in an attempt to identify the important summer habitat characteristics (listed above) for the IB.

For the third step of our analysis, we utilized high resolution digital aerial imagery (over the northern two study areas). We used this imagery in part to assess how accurate our landscape classifications had been from the LSTM imagery. However, our primary focus here was on the local (microhabitat) characteristics that are seen as significant indicators of Indiana bat summer habitat quality: i.e., edge characteristics and identification of snags, snag location and overall snag potential.

5.0 Results

For the Level 1 portion of our analysis, we used imagery taken by Landsat 7 ETM+. Each scene covers an area of 185 km by 185 km, or 34,225 sq. km. LSTM has 7 multispectral bands (plus one panchromatic band). The green band, red band and near-IR band images can be used to create a false color composite so areas of vegetation, urban use and water can be revealed quite easily. Usually, an unsupervised image classification technique can be applied to the composite image to quantify the different types of land use and land cover. However, the 30 m spatial resolution means that only gross level land use classification can be performed (as related to what one might need for IB habitat). Landsat images are very cost-effective in that they are both relatively inexpensive and they cover such large areas.

With regards to IB summer habitat specifically, we were able to map general land cover and land use characteristics (e.g., agricultural use vs forest cover vs wetlands), which would be most valuable in eliminating areas with low bat habitat potential (e.g., urban and agricultural areas). For example, wetlands, clear ground, differing types of agriculture and wooded cover are clearly visible in the TM image (Figure 2) below.

However, other studies have shown (Gobron, et al., 2003; Goetz, et al., 2003) that more detailed land cover analysis (such as corn fields vs pasture or mature closed forests vs re-growth, open woodlands) can be identified with LSTM imagery if two images are taken of the same area at different times during the growing season. This multi-temporal approach (within the same year or between two different years) adds a time component that enables a more accurate separation of land cover. The underlying principle is that different land cover types (agriculture types, forest types, etc.) have more unique spectral signatures over time. For instance, corn may have a similar spectral signature to soybeans in the middle of July. However, by late August or early September, corn is typically senescing while soybeans are often still actively growing. This same concept can be applied to forest canopy, grasses, and a host of other land cover types.

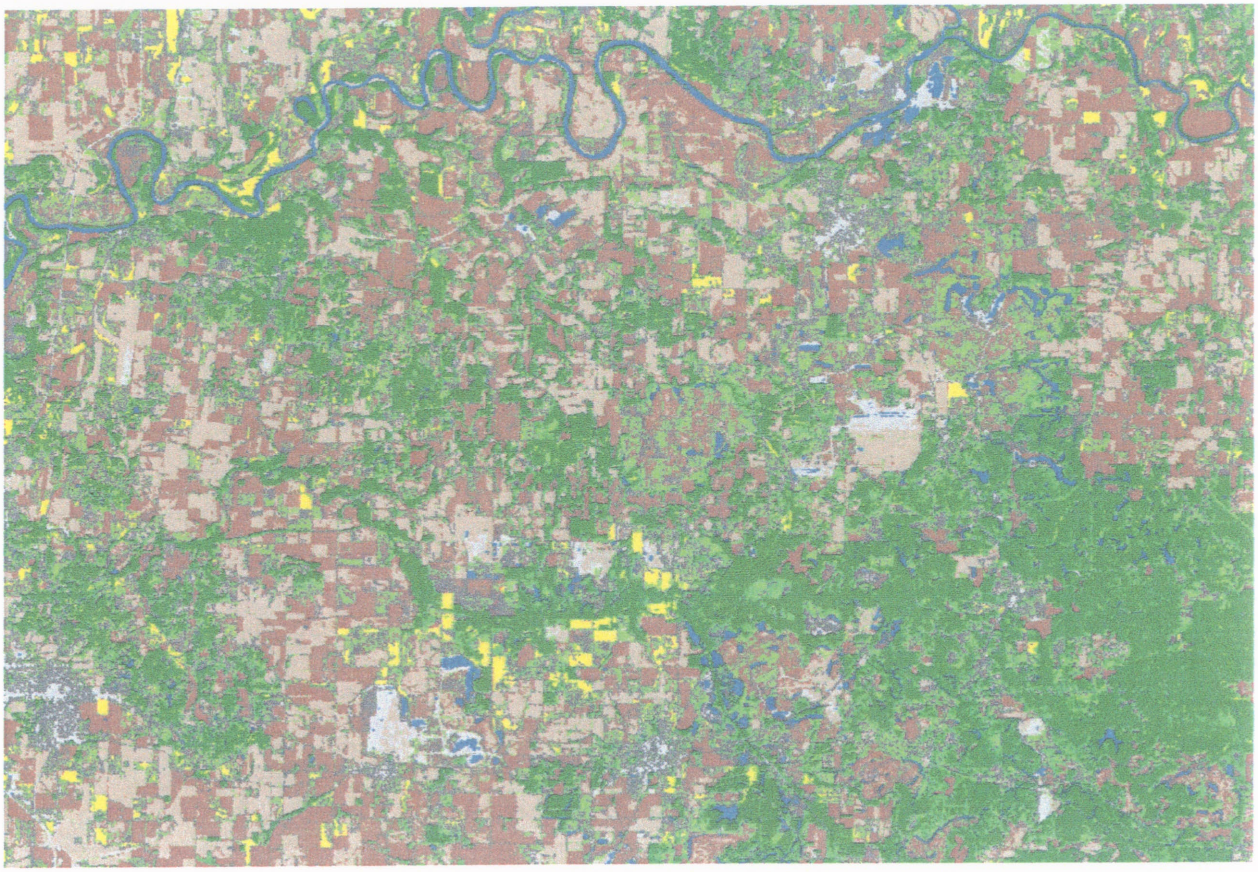


Figure 2
TM Based Land Cover Classification

Even though there are limitations as to what can be identified using Landsat Thematic Mapper data (with respect to potential IB habitat), the value of the resulting classification can be enhanced through GIS manipulation. For instance, there are processes (e.g., spatial filters) that can be used to identify or isolate areas such as forest edge, water edge (shoreline), and forest water interface, to name a few. Other GIS functions that would add value to the land cover classifications from Landsat TM include contiguity analysis (size of a grouping of similar pixels), pixel association (what other land cover types are in close proximity), and adaptive filtering which enables an analysis of percent land cover per unit area (which can be used to rate approximately the percent canopy closure). Equally important is the integration of other GIS layers (such as hydrology, wetlands and flood prone areas, roads, and soils) with the land cover classification identified from the LSTM imagery. The additional layers enable the identification of areas such as flood prone bottom land forests, or more specifically, flood prone bottom land hardwood areas that are within 1000 feet of open water and are within 500 feet of non-forested land cover (i.e., forest edge). While this technology is not capable of revealing individual snags, it can be used to model areas that have a higher potential for IB habitat. (See Figure 3 below.)

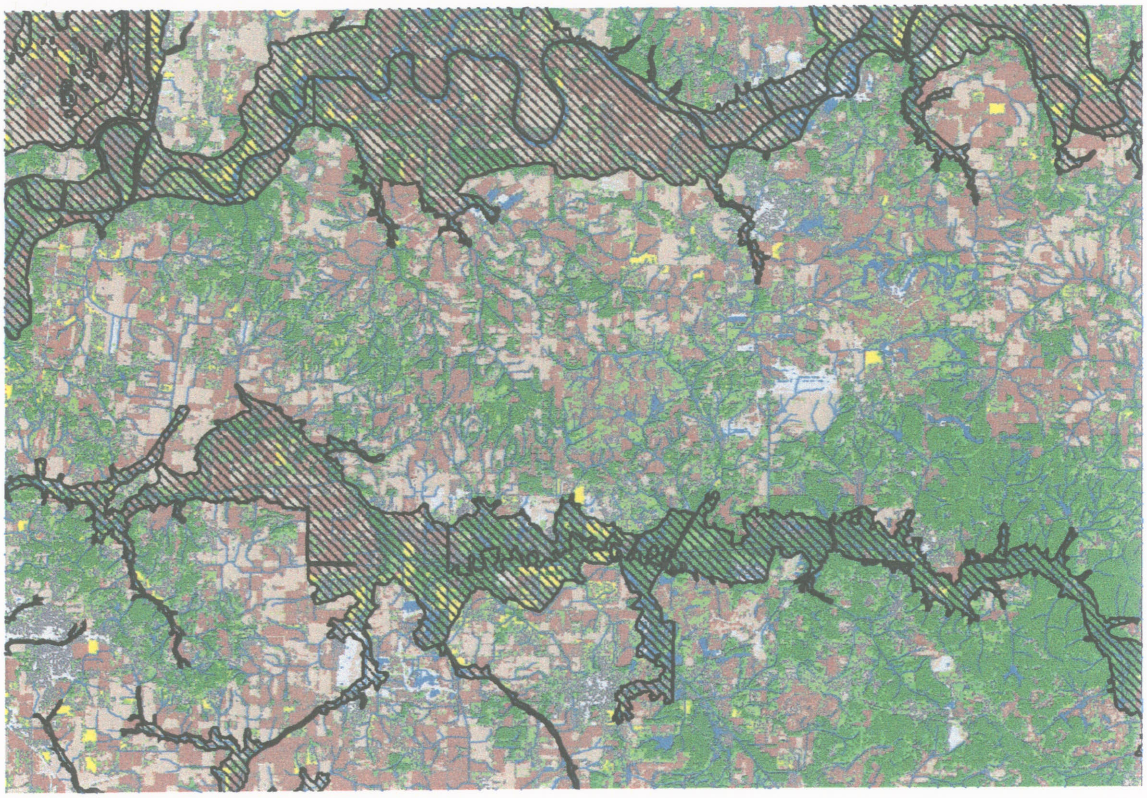


Figure 3
TM Land Cover Classification with Flood Prone Areas and Hydrology Overlay

As part of our Level 1 analysis, we also included an evaluation of SPOT 4 imagery. Each scene covers an area of 60 km by 60 km, or 3600 sq. km. SPOT has 4 multispectral bands, and again, the green band, red band, and near-IR band images can be used to create a false color composite so areas of vegetation, urban use and water can be readily seen. SPOT imagery provides an image resolution of 20 m for the multispectral bands, which is considerably better than the 30 m spatial resolution of Landsat TM. Therefore, an unsupervised classification technique applied to these composite images should yield a higher quality analysis of land use and land cover. However, we found that the landscape level analysis for Indiana bat habitat was not significantly more accurate than the single date Landsat Thematic Mapper data. In addition, the Spot images are much more expensive than LSTM and given that they cover a smaller area, the cost increases further with the increased number of images (about 9 SPOT images to cover one LSTM image).

For our Level 2 analysis, we focused on QUICKBIRD (QB) satellite imagery. QUICKBIRD was launched to provide very high-resolution satellite imagery. Each of the 4 multispectral bands has a spatial resolution of 2.44 meters (8 feet). The panchromatic band has a spatial resolution of 0.61 meter (2 feet). Given this higher level of resolution, QB images can offer greater detail and increased accuracy during the land cover classification process, and these results can be improved with visual assessment of the images.

With regards to IB summer habitat specifically, we were able to more accurately map land cover and land use characteristics, which enabled us to more readily identify edges and the overall level of patchiness in the study area. In addition, we could identify some forest characteristics, such as general tree age or forest density, but only in relative terms. For example, what we identified as "full canopy closure" generally included forest areas with $\geq$ 90% closure. "Moderate canopy closure" included a range from about 50% to 90% canopy closure and "intermediate canopy closure" included everything under 50% closure. These relative results are due to the fact that it is hard to separate the upper canopy from the understory or bare vs open ground in QB images. We also felt that in some situations, we might be able to identify some species types with a single image, though not with a high degree of precision (e.g., this aspect could be improved with multiple images during the growing season). (See Figure 4 below.)

Figure 4
QUICKBIRD Image

Therefore, though greater accuracy is possible here, this imagery again would be most valuable in eliminating areas with low bat habitat potential (e.g., low patchiness or immature forests). Further, as can be seen with the inset image below (see Figure 5), the increase in accuracy is not significantly better than that which can be obtained from LSTM imagery. This slight improvement will in general not be sufficient to offset the increased costs. QB images are much more expensive than SPOT imagery, in large part due to the fact that they cover a much smaller area (more than 50 QB images to cover one SPOT image). This in turn makes them even more expensive with compared with LSTM images. Therefore, these would be most valuable for smaller study areas.

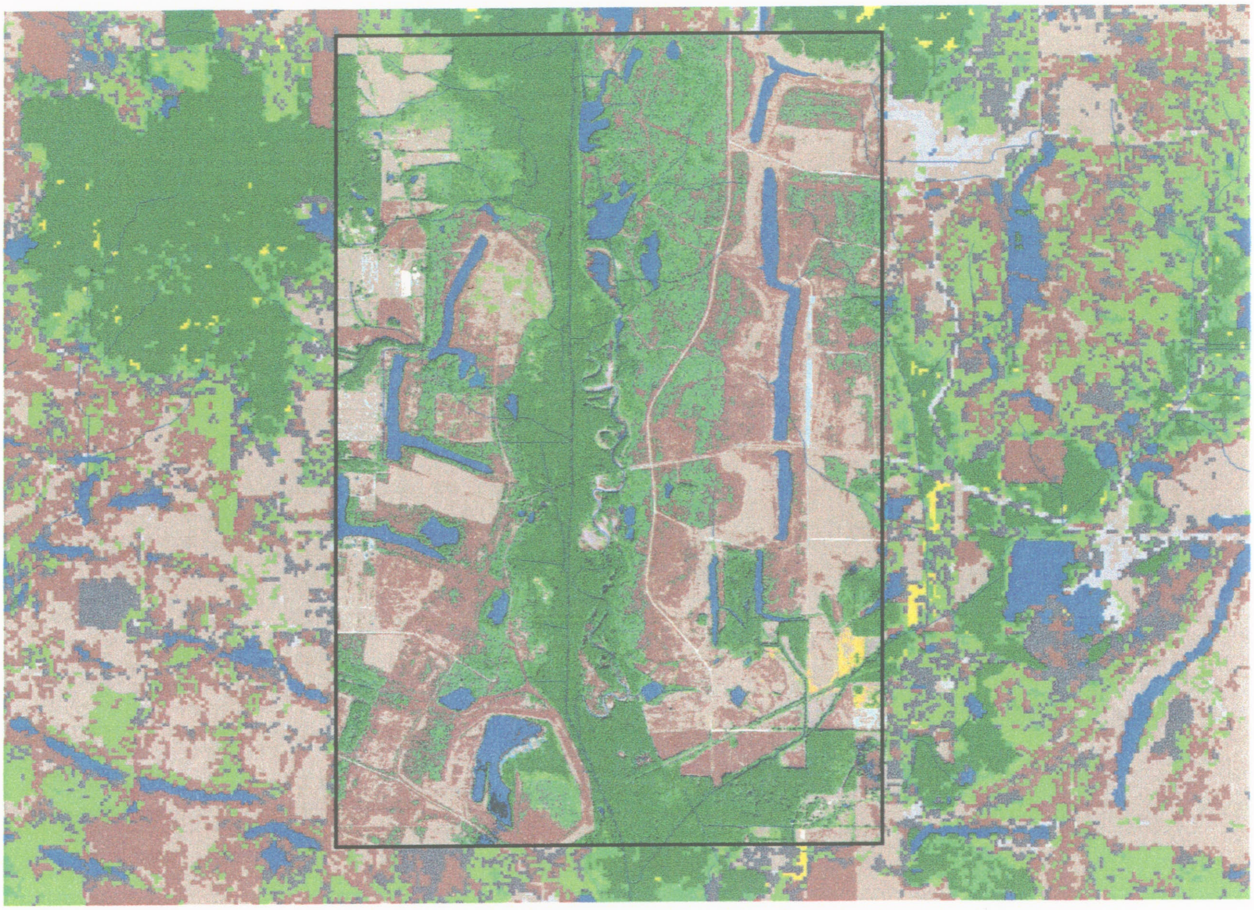


Figure 5
Quick Bird Classification Inset into Lansdat Thematic Classification.

For our Level 3 analysis, we utilized high resolution digital aerial imagery. Each of the 4 multispectral bands has a spatial resolution of 0.323 meters (1 ft). Both of the four square mile study areas required approximately 160 individual images that were mosaiced together to form one large contiguous image. This type of multiple connected images can only be analyzed visually, but the higher level of resolution enabled us to identify a much greater level of detail (e.g., individual trees) and with increased accuracy regarding the location of the identified features (e.g., along the edge of a wetland).

With regards to IB summer habitat specifically, we were able to identify and accurately locate hundreds of snags in the study areas. We could easily assess and rate forest characteristics such as cover, tree density, stand maturity (percent of old trees) and tree species in some cases. Both the amount and location of edges can be easily seen, so the level and type of patchiness can be identified and quantified. For example, Figure 6 below shows Study Area # 2 (Pike/Gibson County line) in its entirety in color infrared. All of the located snags are indicated (yellow dots) and note the clarity of the edges and the clear differences in vegetative cover.

Figure 6
CIR Image of High Resolution Data with Identified Snags (Study Area on boarder of Pike and Gibson Counties). The Study Area is 2 Miles on a Side.

Figure 7 below is another color infrared image of Study Area # 2, but in this case, shows a smaller subset of the full image (showing only 1/16 of the total area), at a higher resolution. Notice the increased visibility of the snags, the edges and the stark differences in the vegetation cover. Figure 8 (below) is the same image in normal color.

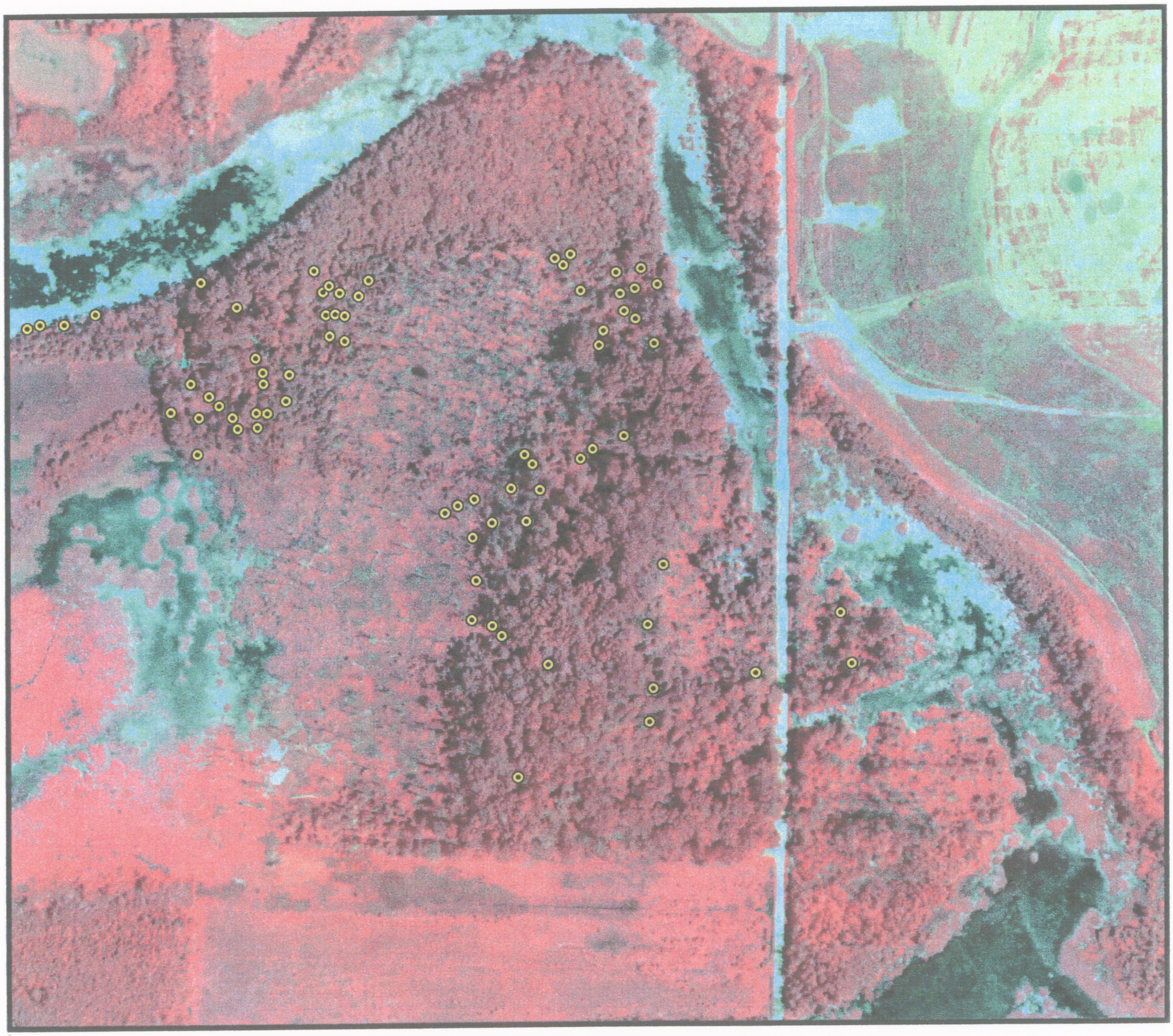


Figure 7
CIR Image of High Resolution Imagery with Identified Snag Locations within Forested Canopy. (This image is located in Pike and Gibson Counties and is approximately ½ Mile on a Side)

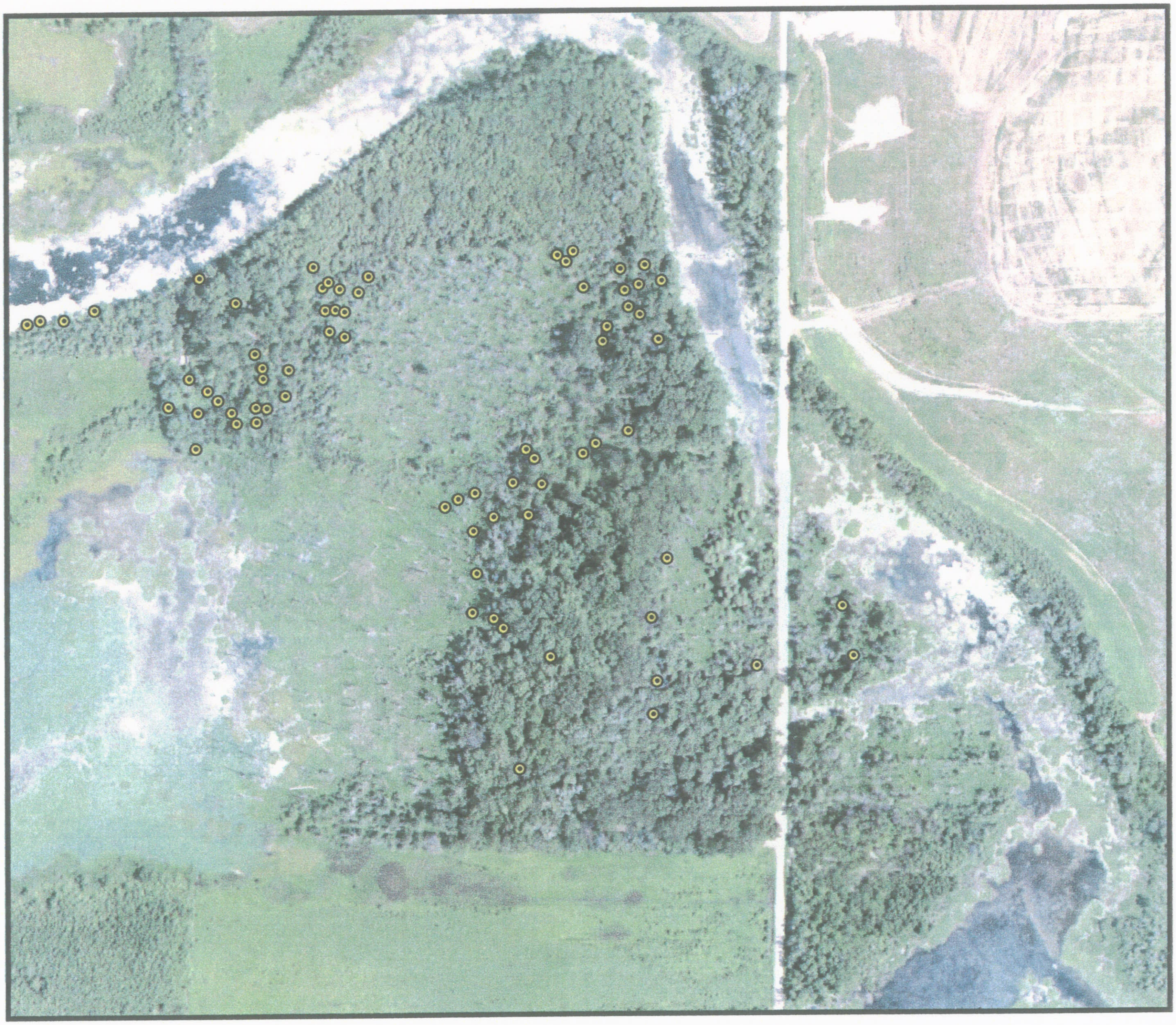
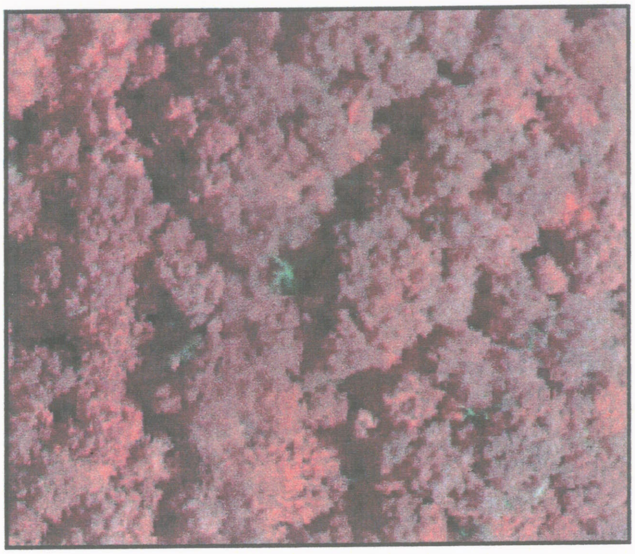
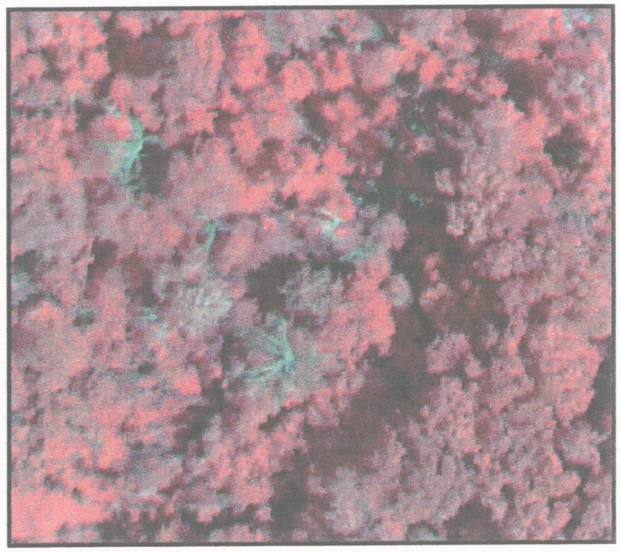


Figure 8
CIR Image of High Resolution Imagery with Identified Snag Locations within Forested Canopy. (This image is located in Pike and Gibson Counties and is approximately ½ Mile on a Side)

Figures 9 and 10 below are again subsets of the previous images, increasing the resolution by two orders of magnitude. Individual snags can be readily seen and tree species identification is clearly possible, along with other microhabitat characteristics (e.g., solar exposure, cover gaps). Figures 11 and 12 below are ground level photos of individual snags showing the surrounding cover characteristics.





Figures 9 and 10
Two Subsets of the High Resolution Imagery Showing Individual Snags. Each subset is Approximately 250 feet on a side.

Figures 11 and 12
Ground Photographs of Snags

From the preceding images, it is clear that only through the use of high resolution digital aerial imagery is it possible to accurately identify the microhabitat characteristics seen as critical to Indiana bat summer habitat. Further, this is the most accurate way to obtain a detailed analysis for some of the critical macrohabitat characteristics as well. However, this type of imagery is by far the most expensive, and given the amount of data collected, can only reasonably be used on very small survey areas.

6.0 Conclusions

Based on the above findings, it is clear that of the currently existing remote sensing technologies, high resolution digital aerial imagery is the only means available with a high probability of identifying high quality habitat for summer use by the Indiana bats. This is because both the presence of suitable snags and the overall potential for snags (now and in the future) is best identified through this imagery and these are the two aspects most significantly correlated with bat use and presence. However, the survey areas effectively covered by this method are so small as to make large scale surveys both time consuming and prohibitively costly.

However, we also found that the lower resolution satellite imagery (LSTM) could be used to classify landscape level features which could then be used to identify areas that are unsuitable for IB use during the summer. Therefore, we believe that our results suggest that surveys to identify and rank habitat for summer use by Indiana bats should begin with this Level 1 assessment. The effectiveness of this assessment could be enhanced by acquiring and analyzing multi-temporal images covering the same survey area.

Next would come the Level 2 assessment, using high resolution (QB) imagery to both verify the LSTM results and further assess those areas not eliminated, i.e., those which have higher potential for IB summer use. In addition, both types of satellite imagery could further enhance their results by indicating only the forested acres (within the areas not eliminated) for more detailed study.

Both of these levels of assessment could be further enhanced by adding a GIS analysis. This could include adding additional data layers (such as soils, elevation, roads, or hydrology) that would help further refine the areas with the highest or lowest use potential. For example, the hydrology could indicate flight corridors beneath the forest canopy or high potential areas could be further refined by buffering away from roads.

Next, would come the Level 3 assessment, using high resolution digital aerial imagery. This type of assessment could be conducted in a number of ways. One (3a) would be using a sampling method, only surveying selected areas within the forest study area (identified In Levels 1 and 2) and using the high resolution data (e.g., the number of snags) to estimate snags in the forest as a whole. This would enable the researchers to rank the habitat's potential for IB use. Another (3b) method would be to take images of the whole area, including the edges, to get a complete and highly detailed assessment of the habitat as a whole, leading to a more specific habitat evaluation.

Finally, the next step would be the ground surveys to test the above predictions regarding the habitat elements used to rank the area. For example, we were unable to see snags in the locations where IB roost sites were located according to the mapped information we were given (through OSM). Eventually, on-site surveys, to assess the presence of Indiana bats in indicated areas, would offer the final ground test of the predictions regarding summer habitat potential.

7.0 Recommendations for Future Studies

For this pilot study, the study sites themselves were located over known past roosting sites and in areas where the Indiana bat's presence had been confirmed by mist netting. This was done so that we would be analyzing images to identify summer habitat characteristics for areas which actually supported bat populations. These results could then function as a control for future tests of our conclusions.

For future studies, we would recommend an expansion of this study, starting with the mapping of a larger (multiple county) study area, using our Level 1 and Level 2 analysis. We would then acquire high resolution aerial imagery (for snag and microhabitat assessment) of the areas identified and mapped from the lower resolution satellite imagery. This would require a more specific aerial image acquisition process that only captures data over forested areas which meet the potential bat habitat criteria, in order to be more cost effective. For example, in our pilot study, well over half of the acres that were mapped in the 4 square miles for each of the two study sites were not considered prime bat roosting sites – they were actually bare soil and agriculture.

In addition, using this larger multi-county area will enable us to include both areas with known use by Indiana bats in the summer and areas without, offering a more complete test of the method. This will further enable us to set up a clearer means for ranking the true potential for bat habitat. Once tested and supported by ground surveys, this method could then be used for better management decisions, both pre and post use of the habitat. For example, during the permitting process, the proposed project site could be evaluated and if it has high potential, no permit need be granted or a higher mitigation value could be applied. Further, after the project is completed, the initial survey data and site ranking could be used as the ultimate goal, and compared with the current level of habitat restoration to evaluate the remediation process.

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