A Comparative Analysis in Methodologies Used to Measure Forest Canopy Gaps in the Root River Floodplain Forest

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Abstract

Canopy Gaps in an Upper Mississippi River floodplain plot were measured as part of a songbird nest-site selectivity study. Two methods of measuring floodplain forest canopy gaps were compared. One method used a ground crew to sweep the plot and record spatial and botanical information of canopy gaps > 10 meters in diameter. The second method used 1:15,000 scale color infrared stereoscopic aerial photographs, a high resolution scanned image and a Geographic Information System (GIS) to interpret canopy gaps > 10 meters. Botanical characteristics of the gap's interior were not collected with the second method.

A nearest feature distance analysis was performed on both the ground sweep and air photo data sets. One hundred random points were selected from within the plot and the distances from the random points to the nearest gap feature were calculated. A paired two tailed t-test of nearest feature distance showed a significant difference between data sets ($P < 0.001$). When a nearest feature analysis was performed from songbird nest sites to the nearest gap feature a paired two tailed t-test showed no significant difference between the air photo derived and ground sweep methods ($0.05 < P < 0.10$).

The air photo/GIS method performed a more complete survey of the canopy gaps then the ground sweep. The air photo/GIS method omitted fewer gaps in its survey then did the ground sweep. The ground sweep method and the air photo/GIS method had comparable rates of commission error. The air photo/GIS method recorded more accurate and detailed spatial data of the canopy gaps then the ground sweep.

Introduction

Small canopy gaps in continuous forest are formed by disturbances such as windfall, disease, selective harvest, etc. These small breaks in the canopy are important ecological landscape features. Small-scale canopy gaps within large forests are rich habitats for birds (Dellasala et al. 1996). Many species of bird show a marked preference for nesting or foraging in areas near gaps. American redstarts and Kentucky warblers have been documented to prefer gap habitats within large, contiguous forests (Hunt 1996, Kilgo et al. 1996). It has been shown that plant species diversity appears to be greatest in canopy gaps of ≈ 0.1 ha. Plant diversity decreases as canopy gaps diverge from this size (Busing et al. 1997). The shape and location of canopy gaps has a dramatic influence on how the gap will regenerate. Spatial characteristics are also an important influence on the diversity of the plant species in and around gaps (Blackburn 1996).

During the 1996-98 field seasons fledgling success data were collected for neo-tropical migrant bird species of the upper Mississippi River valley. This was done for a research project directed by Dr. Melinda Knutson of the Upper Midwest Environmental Science Center, La Crosse, WI (study number WE-97-00095-10). A majority of the fieldwork involved nest searching/tracking, point count censuses, and vegetation measurements. The study areas were located in mature floodplain and upland forests. During the course of the study it was observed that the greatest concentration of nesting activity was located near breaks in the forest canopy (Knutson 1995, Knutson et al. 1996).

Inspired by this observation, the initiative was taken to measure the size, location, and composition of the canopy gaps on twelve plots involved in the nesting success study. The gap data would then be used to determine if there are any relationships between the nest and the canopy gap locations. All floodplain plots (10 plots) as well as two upland plots were surveyed for canopy gaps. The protocol for the nesting success study was amended to include the methods used for identifying and measuring gaps in the forest canopy.

Measuring canopy gaps from the ground was a labor-intensive process. It took many person/hours to systematically sweep through the plots and record gap characteristics. During the process of collecting ground data the idea was proposed that the spatial information of each gap might best be derived from the interpretation of air photos. Air photos had already been taken of the plots that were being surveyed for canopy gaps. Some of the plots had been flown only two months before the ground surveys were conducted.

The Upper Midwest Environmental Science Center then allocated money to interpret canopy gaps from the air photos of one floodplain plot and compare that data set to the data derived from the ground sweep. If the air photo data were comparable or superior to that of the ground sweep the photo interpretation method would be used to collect spatial information of canopy gaps for the remaining floodplain plots. The study plot used for this comparison of methodologies was the Root River plot, located in an area that is just SW of where the Root River enters the Mississippi River in Houston County, MN (Figure 1).

Figure 1. Location of Root River Plot. Plot boundary represented by white crosshatched polygon.

Methods

The Gap criteria

The criteria for how gaps were to be defined were determined prior to the ground survey. The criteria were set to give the ground crew a template for what they where to look for when collecting data. They were set with no foreknowledge that the gaps would later be interpreted from photos. Both methods used the same set of criteria. The criteria were as follows:
1) The gap should be able to hold a circle that has a diameter ≥ 10 meters.
2) There must be at least a 5 meter height difference between high canopy trees and the next strata of vegetation.
3) Each gap will have ≥ 80% of its perimeter composed of high canopy trees.
4) Gaps are not to be part of an open-ended system (e.g. large rivers, trails, logging roads, and wetlands).

The Ground Surveyed Data

The spatial information for the ground survey of the Root River plot was collected during the period of July 16th, 1997 - August 21st, 1997. Multiple crews coordinated their efforts to systematically sweep the plot. The sizes of gaps were recorded by measuring the maximum length across each gap and maximum width perpendicular to that length. Distance measurements were obtained by walking across each gap and then converting the individual's strides to meters (e.g. for person X, 7 strides ≈ 5 meters). Each gap's shape was recorded with a pencil sketch. The magnetic orientation of the maximum length was recorded with a standard pocket compass. The approximate location of each gap's centroid was recorded with the use of a Rockwell PLGR+96 GPS receiver (Projection: UTM Zone 15, Datum: NAD27). Each centroid's position within each gap was added to the pencil sketches. The centroids were not directly tied to the other spatial measurements (Figure 2).

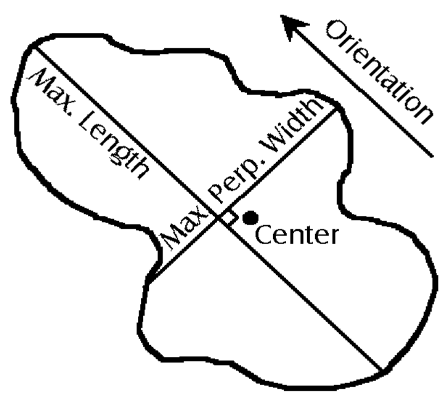

Figure 2. The parameters recorded by the ground survey to describe gap spatial characteristics.

The ground survey also recorded the botanical characteristics of the flora within each gap. The gaps were divided into four quads of approximately equal area. Botanical measurements included 21 variables to describe ground cover, shrubs, trees, snags and stumps within the gaps (Knutson 1995, Knutson et al. 1996).

(GIS)Layers - Ground Surveyed Data

A point coverage was generated from the gap centroid locations using ArcInfo v7.1.2 software. The spatial and vegetation tabular data were then joined to this point coverage.

A polygon coverage was also created from the gap data collected by the ground crew. This was performed using ArcView 3.0a software. An Avenue script was written that constructed ovals from the tabular data collected by the ground survey. The script first created vector rectangles from the maximum length, maximum perpendicular width and centroid data. A vector oval bounded by the rectangle was then constructed. The script then converted the ovals into grids (raster format) with a 0.1 meter cellsize. The grid ovals were then rotated to their true north orientation and resampled with a nearest neighbor algorithm. Finally the raster ovals were converted back into vector shapes. Each gap was then represented by a vector oval. The length of each oval is equal to that of the maximum length recorded by the ground survey. The width of each oval is equal to the maximum perpendicular width. The orientation of the ovals was converted from the magnetic north to true north. Each vector oval was centered on the centroid recorded by the ground survey unless the sketch indicated that the gaps centriod location was significantly different then the intersection of the length and width measurements.
The sketches were referenced to determine if the ovals needed to be shifted to compensate for any difference between centroid location and the location of the intersection of the maximum length and maximum perpendicular width. The script constructed the ovals at the intersection of these two measures. The ovals were manually shifted to compensate for any discrepancy. Only 4 of the total 34 ovals needed to be shifted in this manner.

Two GIS data layers were created from the ground surveyed data. A point data layer of gap centroids and a polygon (oval) data layer. The feature attribute tables were joined to the botanical data.

Photo Interpreted Canopy Gaps

The air photos used to delineate canopy gaps are the property of the USGS, Upper Midwest Environmental Science Center (UMESC), La Crosse, WI. They were taken on August 28th, 1997 using Kodak Aerochrome Infrared 2443, 9in x 9in film. The prints have a scale of approximately 1:15,000 and are in stereo. The print with the study plot situated closest to the nadir point was scanned on a Magna 636 drum-scanner. The scan created an 8-bit grayscale, 800 ppi, 54 Mb TIFF image. The nominal scale of the scanned image was 1:15,380. At 800 ppi each pixel of the scanned image represents 0.49 meters^2 on the ground.

The image was rectified with ground control points (GCPs) collected from a Trimble GeoExplorer global positioning system receiver. The GCPs were post-process differentially corrected with Trimble's Phase Processor v.1.0 software. The base station files used to differentially correct GCPs were obtained from the UMESC. The GCPs were collected on January 1st, 1998 between the hours of 9am and 3pm. A total of 8 points were collected. The GCPs were collected from positions that encircle the study plot and range 150 to 717 meters from the plot boundary. The receiver's operating parameters were set to the following:

Recording at 15-second intervals.
SNR Mask: 6
Elevation Mask: 10 degrees
PDOP Mask: 6
PDOP Switch: 6
Dynamics Code = 4 (Static)

The points were collected using the receiver's High Accuracy Mode. In this mode the receiver is mounted on a tripod of known height and records a number of readings at a stationary position. The Phase Processor then averages these positions after each is differentially corrected. The Phase Processor uses both the satellites' pseudo-random code as well as the code's carrier wave to bring the receiver and satellite into near perfect sync. This process of using the carrier frequency to synchronize the pseudo code and differential correcting to a known location allows for the receiver/software to obtain sub-meter positions (Hurn J. 1993).

The scanned air photo was then rectified with ERDAS Imagine software. The Root River bottoms have little topographic relief. As a result the image was rectified with the affine transformation algorithm (ERDAS Inc. 1971). Image/GCP links that showed a high residual Root Mean Square (RMS) error were shifted. Image links were not shifted more than two pixels (1.39 meters ground distance).

Check points were taken to compare the positional accuracy of the rectified image and the Rockwell PLGR+96 GPS receivers used by the ground crews to record gap centroids. Five check points were taken along State Route 26 in Houston County, MN. The points were taking at locations where driveway centerlines and the highway's shoulder edge intersected. The distance between the positions recorded by the GPS receiver and the equivalent positions obtained from the rectified image were calculated.

The stereo air photos and a Topcon Model 3 Mirror Stereoscope were then used to identify all perceivable gaps, regardless of size. Once a gap was identified on the photographs it was located on the scanned image and then digitized on screen. Once all gaps were digitized they were subset to represent the criteria used by the ground survey.

Three final products were produced from the photo interpretation/on-screen digitizing method: a polygon layer of all perceivable gaps, a polygon layer that meets the ground survey criteria, and a high-resolution geographically referenced image.

Ground Truthing & Nearest Feature Analysis

All of the gaps of both data sets were revisited and verified against errors of commission on the days of May 12 and13th, 1998. The data sets were checked for errors of omission by cross checking. The photo derived data set was inventoried to make sure that it contained all verified gaps of the ground surveyed data set. Then the ground surveyed data set was cross-checked against the verified gaps of the photo derived data set. One hundred random points were generated within the Root River plot boundary. An Avenue script was written to perform a nearest feature distance analyze from each random point to the nearest gap polygon. The analysis was performed for both the ground-surveyed data and the photo interpreted data. A paired two tailed t-test was performed on the nearest feature distances of the data sets.

A test run of a future application of this data was also performed. This entailed a nearest feature analysis from songbird nest site locations to the nearest canopy gap feature. The test run was performed on both ground-survey and photo interpreted data sets. A paired two tailed t-test for means was conducted between the two data sets to determine if there was a significant difference between the mean nearest feature distances.

Results

Image Rectification Errors

The expected accuracy of the differentially corrected ground control points was <1 meter of error. In most cases it was <0.3 meter. All points collected at the GCP locations were accepted by the Phase Processor and were used to calculate the GCP final positions. Distance from the GCP locations and the base station's location at the UMESC was < 14.8 km (Table 1).

The process of rectifying the image with the above GCP locations yielded a RMS error of 0.2728 meters (ground units). This error is associated with the reference grid that provides real world positions for each pixel of the scanned image (Diggelen 1998).

Check Point Distances

The points that were collected by the Rockwell PLGR+96 GPS receiver compare favorably with the locations obtained from the rectified image. The average error estimate of the PLGR+96 receiver while collecting check points was 8.6 meters. The distances between check points and image points were within the error estimate of the PLGR+96 receiver. The average distance between check point and image point was 2.11 meters (Table 2).

Errors of Commission and Omission

The ground survey data had a commission error rate of 5.9%. The air photo derived data set had a commission error rate of 8.9%. The rates of omission for the ground survey data were 29.3%. The rate of omission for the air photo derived data set was 6.3%.

Nearest Feature Analysis

The results of the nearest feature analysis between 100 random points and the gap features of each data set were summarized (Table 3). The ground survey data had a higher mean value for the distance to nearest gap feature. There was a 16.16 meter difference between the mean distance from a random point to a gap feature of the two data sets. The standard deviation of the ground surveyed data was nearly 1.6 times greater than that of the air photo data set. The data sets had similar minimum, maximum and range values.

The results of the paired two-tailed t-test rejects the hypothesis that the mean of the differences between paired nearest feature distances equals zero ($P < 0.001$). Yet the Pearson Correlation shows a strong positive correlation between the nearest feature distances of the two data sets (Table 4).

The results of the analysis were broken down into three tables: nearest feature distances from all nests, from nests located within gaps and from nests located outside of gaps (Tables 5-7). There are subtle differences between the number of nests that fall within or outside of the gaps. This is do to the spatial differences of the ground surveyed and photo interpreted data sets.

Table 1. Description of ground control points and their expected accuracy. X and Y coordinates are UTM coordinates.

Point ID	X Coord	Y Coord	Dist. To Base (m)	Count / Rejected	Expected Accuracy (m)
1	639619.12	4847248.64	13,211.48	197/0	<0.3
2	639970.93	4847067.41	13,244.65	174/0	<1.0
3	640345.58	4847002.01	13,173.62	198/0	<0.3
4	640754.75	4846529.37	13,490.38	185/0	<0.3
5	640559.30	4845968.44	14,083.72	140/0	<1.0
6	640154.94	4846160.86	14,030.66	150/0	<0.3
7	639716.13	4846152.56	14,189.75	150/0	<0.3
8	639822.09	4846546.20	13,784.0		

Table 3. Summary statistics from 100 random points to nearest gap

Summary Statistics	Air Photo	Ground Su
		44.65
		4.02
		30.41
		40.25
		1619.70
		144.59
		0.30

Table 2. Comparing the difference between check points and image points. The check point errors are estimates recorded by the GPS reciever..

Image Point	Check Point	Check Point Error (m)	Distance Between Points (m)
11	21	8.6	2.59
12	22	8.9	3.04

Table 4. Paired two-tailed t-test of Near Feature Distances (NFD): From 100 random points to gap feature of both data sets ($P < 0.001$).

Statistical Measure	NFD Ground Survey Data
Mean of Photo NFD (m)	28.49
Mean of Ground NFD (m)	44.65
Variance of Photo NFD (m)	660.86
Variance of Ground NFD (m)	1619.70
Photo Observations	100.00
Ground Observations	100.00
Pearson Correlation	0.80
Hypothesized Mean Difference	0.00
df	99.00
t Stat	3.385
$t_{0.001(2),99}$	3.349

Table 5. Nearest feature distances from nest sites to nearest canopy gap (air photo/ground survey). This table is of all nest sites regardless of whether they are located inside or outside of a canopy gap interior.

		Average Distance (m)		SD (m)	
Species	Count	Photo	Ground	Photo	Ground
American redstart	25	13.47	18.18	19.58	35.94
American robin	5	21.20	30.64	32.62	31.26
black-capped cickadee	1	6.76	5.01	0.00	0.00
blue-gray gnatcatcher	1	16.78	25.69	0.00	0.00
brown creeper	1	5.71	17.47	0.00	0.00
eastern wood-peewee	2	55.57	47.86	44.43	61.68
great-crested flycatcher	2	4.28	1.77	2.89	0.00
gray catbird	7	4.57	6.61	4.60	1.65
northern cardinal	1	0.24	1.78	0.00	0.00
rose-breasted grosbeak	1	11.53	18.92	0.00	0.00
yellow warbler	6	9.35	11.26	14.34	13.62

0.10) showed that there is not a significant difference between photo interpreted

Table 6. Nearest feature distances from nest sites located inside gaps to nearest gap edge (air photo/ground survey).

Species	Count		Average Distance (m)		SD (m)	
	Photo	Ground	Photo	Ground	Photo	Ground
American redstart	4	4	2.22	3.56	1.33	1.73
American robin	0	1	4.62	11.75	0.00	4.24
eastern wood-peewee	2	1	0.00	4.24	0.50	0.00
great-crested flycatcher	1	1	2.23	1.77	0.00	0.00
gray catbird	2	4	7.32	6.57	6.75	1.25
northern cardinal	1	1	0.24	1.78	0.00	0.00
yellow warbler	1	0	1.63	0.00	0.00	0.00

Table 7. Nearest feature distances from nest sites located outside of gaps to nearest gap edge (air photo/ground survey).

Species	Count	Average Distance(m)		SD (m)	
		Photo	Ground	Photo	Ground
American redstart	25	15.61	20.96	20.73	38.71
American robin	5	32.25	35.36	40.87	33.97
black-capped cickadee	1	6.76	5.01	0.00	0.00
blue-gray gnatcatcher	1	16.78	25.69	0.00	0.00
brown creeper	1	5.71	17.47	0.00	0.00
eastern wood-peewee	2	55.57	91.47	44.43	0.00
great-crested flycatcher	2	6.32	1.77	0.00	0.00
gray catbird	7	3.48	6.66	3.89	2.42
rose-breasted grosbeak	1	11.53	18.92	0.00	0.00
yellow warbler	6	10.90	11.26	15.46	13.62

Paired t-test: Nest Sites to Nearest Gap

The paired t-test for means (0.05 < P <

data and the data collected from the ground when comparing the distance from nest site to nearest gap feature (Table 8).

Table 8. Paired two-tailed t-test of nearest features distances: nest sites to gap features ($0.05 < P < 0.10$).

Summary Statistics	**Ground Survey**	**Air photo**
Mean (m)	17.11	13.30
Variance (m)	870.44	422.65
Observations	52.00	52.00
Pearson Correlation	0.87	
Hypothesized Mean Difference	0.00	
df	51.000	
t Stat	1.781	
$t_{0.05(2),51}$	2.008	

Discussion

Ground Survey Strengths

The most valuable characteristic of the ground survey data is the vegetation measurements taken within the gaps. The scale of the air photos precludes delineation of the botanical structure of small canopy gaps. A gap that is ten meters on the ground is a mere 0.67mm on a 1:15,000 scale air photo. This is far too small to interpret the vegetative composition of the gap's interior. In addition to the ground cover data, the ground crew obtained accurate counts of shrubs, small trees and snags within the gaps. Again, this information could not be obtained from the scale photography used in this project.

The ground survey had a very low rate of commission errors. Two of the gaps were found to be too small upon verification. This might be attributed to the measurement techniques used on the ground (pacing distances), vegetation growth (gaps were verified the following spring), or individual perception of where the high canopy boundary begins.

Ground Survey Weaknesses

The gap omission rate of the ground data was high. This may be a result of the difficulty in coordinating multiple crews to effectively sweep the plot, walking straight transects and keeping track of which gaps have and have not been assessed. In addition, the detection of a 5-meter drop between vegetation stratum is difficult from a bottom-up perspective.

There are concerns about the spatial accuracy of the data collected from the ground. These stem mainly from the instruments that were used to collect data (pocket compass, pencil sketch and pacing).

Multi-path of the satellite's timing signals appears to have affected the positional accuracy of the PLGR+96 GPS receivers. Possible evidence of the effects of multi-path can be observed when we look at relative positions of checkpoints to image points, as well as the positions of individual gaps between data sets. The relative positions of checkpoints collected with the PLGR+96 receiver compare favorably with the locations obtained from the rectified image. The checkpoints were collected from positions that had few sources of multi-path, yet a visual comparison of gap locations (Figure 3 & 4) seems to illustrate positional inconsistencies between data sets. Leaves are a significant source of multi-path of GPS satellite signals and may have influenced

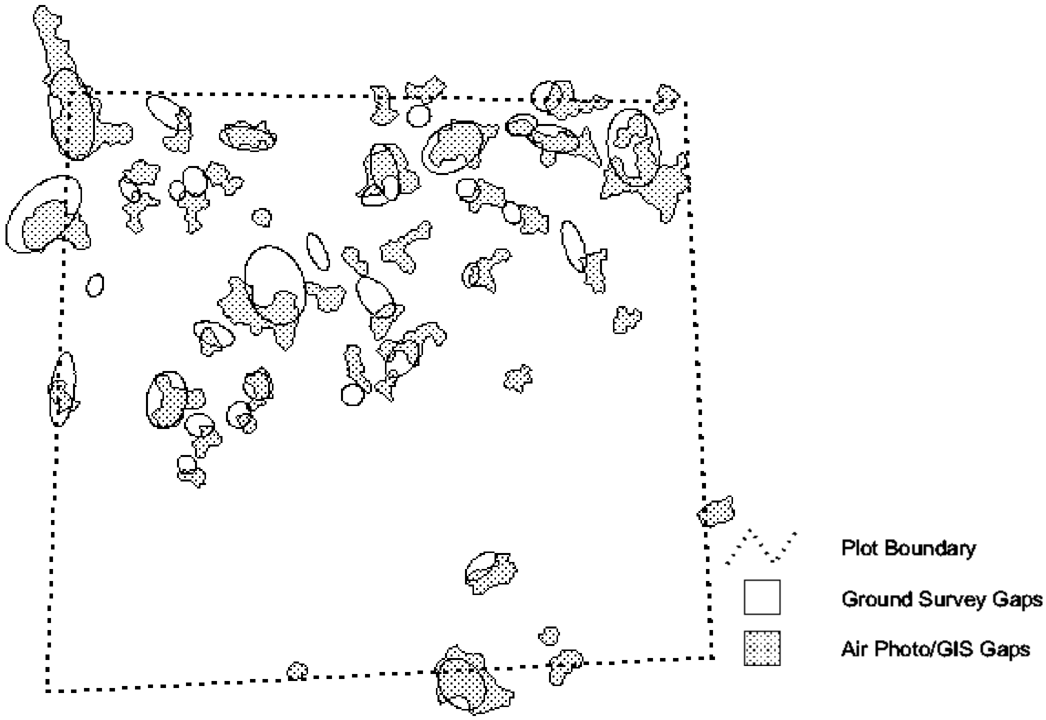

Figure 3. The gaps of the Root River plot. Shaded polygons represent air photo derived gaps and ovals represent ground survey gaps.

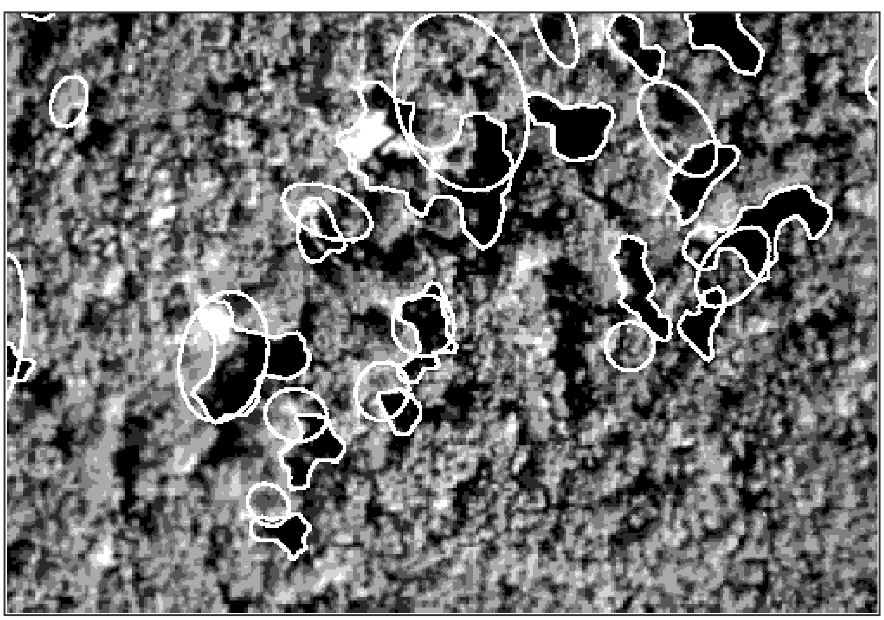

Figure 4. Example of ground survey and air photo derived gaps wit
clearly define canopy gaps on an image it is necessary to view the ir

Their positions within the gap were merely marked on a pencil sketch. Without a direct tie to the length and width measurements the sketch must be referenced to determine final position of each gap. This is another potential source of error.

The final spatial issue regarding the ground survey data deals with the loss of gap perimeter definition. By converting the ground surveyed data into ovals, the perimeter of the gap is greatly generalized. Registering and digitizing each gap sketch would maintain the gap perimeter detail recorded on the ground. However, this would be an enormous task that would introduce spatial inaccuracies in addition to those mentioned above.

Photo Interpretation Strengths

The greatest strength of the photo-interpreted data set is its spatial accuracy. The location, size and shape of the gaps can be accurately recorded with this methodology. The scanned and rectified image should not be significantly influenced by multi-path. This is because the GCPs used to rectify the image were collected during a period of leaf off and each GCP is an average of over 150 differentially corrected points recorded at that position.

Perimeter detail of each gap was maintained in the photo interpreted data set. Perimeter information may prove to be important if these data are used to investigate edge effects of canopy gaps. Another advantage of this method is that all perceivable gaps were first identified and then later sub-setted with a criteria. This method allows for the implementation of multiple criteria creating multiple gap sub-sets. The ground method required that the criteria be set prior to identifying gaps.

The rate of gap omission was much lower for the photo-derived data. The air photo data set had an omission rate that was ≈ ¼ that of the ground surveyed data. Commission rates were slightly higher than that of the ground crew.

Photo Interpretation Weaknesses

A major weakness of the photo-interpreted data was the limits imposed by the scale of the photography. Other errors are also inherent with the interpretation/GIS method. Control Point errors, the RMS error of image rectification, the resolution of the scanned image and digitizing errors effect the accuracy of this method. The subjectivity of the interpreter was also an inherent weakness of photo interpreted data. A 10 m diameter graphic circle was displayed on the screen as a guide to the minimum mapping unit. Yet, even with this guide the amount of detail to include when digitizing the gap perimeter is very subjective.

Paired t-tests

The paired t-test for means performed for the nearest feature distances from 100 random points to the nearest gap shows a significant difference between the two data sets($P < 0.001$). Yet, the paired t-test for means performed for the nearest feature distances from songbird nest sites to the nearest gap did not show a significant difference between data sets ($0.05 < P < 0.10$). The reason that this t-test did not show a significant difference might be attributed to two factors. One factor was that the search effort for bird nests was non-uniform. The second factor is the existence of several gaps in the southern portion of the plot that were omitted by the ground crew. These gaps are located in a section of the plot that was infrequently searched for songbird nests. Thus the nest sites and the ground surveyed canopy gaps were clustered in the same area. Both the air photo data set and the ground surveyed data set indicated a cluster of gaps in the area that was most heavily searched for songbird nest sites. These factors are reflected in the results of the t-test.

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