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INFLUENCE OF THE JUXTAPOSITION OF TREES ON CONSUMER-GRADE GPS POSITION QUALITY

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Abstract. Until now, limited observational data have suggested that the juxtaposition of trees with respect to place where a GPS position fix is collected may affect static horizontal position accuracy of that determined position. Our goal was to assess GPS accuracy with respect to the spatial arrangement of nearby trees, and determine whether correlations existed or whether trends were evident. Therefore, static horizontal position accuracy of a consumer-grade GPS receiver was estimated in a young loblolly pine (*Pinus taeda*) plantation in Georgia (USA) to determine whether the arrangement of trees had any influence on position quality. Thirty visits to twenty-nine test points, randomly ordered, were made to collect the necessary data regarding positional accuracy. No significant relationship was observed between static horizontal positional accuracy and environmental variables (air temperature, relative humidity, and atmospheric pressure) or the planned positional dilution of precision (PDOP) of the NAVSTAR satellite configuration. However, we found moderate correlation between average positional error and a few forest structure measures. For example, we observed that as hardwood (deciduous species) basal area and hardwood tree count within 4 or 5 m of a test point increased, the average positional error tended to increase. No significant correlation was observed using forest structure values obtained within 3 m of each test point. Using rose diagrams (circular histograms), we observed that in some cases there seemed to be a negative attraction between the location of live trees and the position determined by the GPS receiver. Using vectors to represent magnitude and direction of both GPS error and forest conditions, we found evidence to conclude that the average distance and direction to live deciduous (hardwood) trees within this young pine forest may have some influence on position quality.

Keywords: Global positioning systems, GNSS, root mean squared error, static horizontal position accuracy, rose diagram, circular histogram

1 Introduction

Global navigation satellite systems (*GNSS*) have become a pervasive technology in natural resource management and in environmental research studies. Satellite positioning systems are typically referred to as *GPS* (Global Positioning Systems) in North America. They are based on electromagnetic energy emitted by satellites situated (or orbiting) several thousand kilometers above the landscape, and received by devices on Earth in order to determine a position (Bettinger and Merry 2011). While the Russian Federation has a satellite navigation system (*GLONASS*) that is currently used internationally, and while the European Union and China are currently developing global satellite navigation systems (*GALILEO* and *COMPASS*), this study focuses on positions determined using the United States *NAVSTAR* system. The NAVSTAR system consists of 31 satellites, allocated to one of six orbital planes around the Earth. Each satellite broadcasts a unique signal on the L1 frequency (1575.42 MHz) using coarse acquisition (C/A) code. Commercially available GPS receivers can utilize this code to determine both horizontal and vertical positions on the Earth.

GPS receivers are generally classified as survey-grade, mapping-grade, or recreation-grade (or consumer-grade), based primarily on cost and subsequently on the technology available in each. Recreation-grade GPS receivers vary in price from $100 to $600, and provide the least accurate static horizontal positions, generally accompanied with 5-15 m of error (Wing et al. 2005, Danskin et al. 2009b). Most natural resource management organizations use mapping-grade receivers, which range in price from about $1,000 to $8,000, and can now determine static positions within about 2 m of true positions (Ransom et al. 2010). Survey-grade GPS receivers can provide sub-meter accuracy for static positions in forests, yet these receivers are generally more expensive, bulky, heavy, and may require several minutes of data collection at each sampling point. In the last few years, GPS technology assessments have mainly concentrated on static horizontal position determination (Anderson et al. 2009, Bakula et al. 2009, Bettinger and Fei 2010, Klimánek 2010, Pirti et al. 2010, Ransom et al. 2010, Wing 2009), although dynamic assessments (e.g., Tachiki et al. 2005) and assessments of static vertical position accuracy (Bakula et al. 2009, Klimánek 2010, Pirti et al. 2010) have also been performed and reported. The main conclusions drawn from recent studies on the static horizontal position accuracy of GPS technology used in forested environments are as follows:

1. Some (e.g., Oderwald and Boucher 2003) have suggested that under certain conditions differential correction of GPS data may no longer be necessary after the discontinuation of the selective availability process in 2000. Recent tests suggest that differential correction of data collected by a mapping-grade receiver under a forest canopy can improve horizontal position accuracy (Danskin et al. 2009a, 2009b), yet results are not universally conclusive (e.g., Wing et al. 2008).

2. Multipath error in forested conditions can account for over half of the error in static horizontal positions (Danskin et al. 2009a), and the ability of a GPS receiver to reject multipath signals may be the main reason why consumer-grade receivers have lower static horizontal position accuracy than mapping-grade receivers (Bolstad et al. 2005).

3. Slope position (e.g., upper vs. lower) can be influential on static horizontal position accuracy (Deckert and Bolstad 1996, Danskin et al. 2009a, 2009b), with positions determined on upper slopes having higher static horizontal position accuracy (lower error) than positions determined on lower slopes.

4. The number of position fixes (epochs, or waypoints) necessary to effectively determine a static horizontal position under a forest canopy is debatable. A decade or more ago it was suggested that perhaps 300 position fixes were necessary (Sigrist et al. 1999). However, recent research suggests that a position determined from a single position fix may generally be no less accurate than one determined from an average of a number of position fixes (Bolstad et al. 2005, Wing and Karsky 2006, Bettinger and Merry 2012).

5. Although high-precision GPS applications may be affected by propagation delay due to atmospheric conditions (Chen et al. 2008), particularly during the passage of weather fronts (Ghoddousi-Fard et al. 2009), atmospheric conditions have been shown to have little effect on static horizontal accuracy in forested conditions (Bolstad et al. 2005, Bettinger and Fei 2010). In a study of a consumer-grade receiver over the course of one year, Bettinger and Fei (2010) found no significant relationship between static horizontal position accuracy and ionospheric or tropospheric variables (air temperature, relative humidity, atmospheric pressure, and solar wind speed).

6. The type of forest (species or age) under which tests are made can influence the accuracy of static horizontal positions (Deckert and Bolstad 1996, Yoshimura and Hasegawa 2003, Wing et al. 2005, Wing and Karsky 2006, Wing et al. 2008, Andersen et al. 2009, Bettinger and Fei 2010).

7. The height of a GPS antenna, when used in forested conditions, can have an effect on static horizontal position accuracy (D'Eon 1996, Wing et al. 2008).

8. Canopy closure may have an effect on static horizontal position accuracy (Sigrist et al. 1999, Veal et al. 2001). Thus the time of year when data are collected can influence static horizontal position accuracy (Danskin et al. 2009b, Bettinger and Fei 2010), particularly when considering deciduous forests.

Although not rigorously tested, the configuration of vegetation (the juxtaposition of trees with respect to place where a position fix is collected) may affect static horizontal position accuracy, and has been suggested by Hasegawa and Yoshimura (2003), Danskin et al. (2009b), Wing (2009), and Bettinger and Fei (2010) as an issue that still needs to be addressed. As a result, the objectives of this work were to understand whether tree position within the immediate area of GPS data collection processes has an effect on static horizontal position accuracy. One hypothesis tested here suggests that static horizontal position accuracy would not change due to tree position or tree density around the position that needed to be determined, given the GPS receiver studied. Other hypotheses we tested, because they were coincidental to the work and in order to provide further support for the previous conclusions drawn, suggest that static horizontal position accuracy would not change as environmental conditions (air temperature, relative humidity, etc.) change.

2 Methods

Using a known location on the GPS Test Site at the Whitehall Forest GPS Test Site in Athens, Georgia (USA) as a starting point, 28 test points on a 3 m grid were carefully delineated using a steel tape. This test area is situated within a young loblolly pine (*Pinus taeda*) plantation (18 years old, unthinned, 41.3 m^2 per hectare basal area, 1,589 trees per hectare, southwest aspect, 8% slope, 212 m elevation, 95% canopy closure). Within this area, there were also 818 deciduous trees per hectare accounting for 1.6 m^2 per hectare of basal area. A Garmin Oregon 300 consumer-grade GPS receiver was employed in this study because a previous study (Bettinger and Fei 2010) noted that the error when using this receiver was biased at the original test point, but not in other nearby study areas.

The 28 temporary test points and original GPS test point were visited 30 times over the course of a month (mid-June to mid-July 2012), and ten position fixes were collected at each test point during each visit. We chose ten position fixes to determine an average point location because: (a) recent evidence with this exact GPS receiver suggested that the first position fix was not significantly different than an average of 50 position fixes in most forest types, yet minor differences do occur in young pine forests (Bettinger and Merry 2012), and (b) the time required to collect data on 29 test points was extensive. Therefore, ten position fixes was a compromise made in order to capture some of the variation in position determination measurements that will occur. These ten position fixes were averaged to determine the static horizontal position accuracy for each visit to each test point. The order of data collection on each of the 29 test points was randomized for each visit.

In order to ensure consistent parameter settings and environmental variables throughout the study period, near real-time augmentation using the United States Wide Area Augmentation System (WAAS) was disabled. This augmentation service cannot guarantee 100% availability, and the GPS receiver was unable to record when the augmentation system was being used. Position fixes (epochs, or waypoints) were captured manually, with 2-3 second intervals, because the GPS receiver employed does not have the ability to collect data automatically every x seconds. At the beginning of each visit, a warm-up period was required, and during data collection GPS receiver was plumbed approximately 1 m directly over each of the 29 test points using a staff and a plumb bob. The person collecting the data was positioned consistently on the west side of each test point as data was being collected. A concerted effort was made so that the body of the person collecting the data would not interfere with the signals. While ideally a person would be situated between the position to be determined and the lowest point on the landscape (maximizing the view above the horizon), the slope in this area was low (8%) and given the arrangement of test points and trees, the best consistent position for the data collector was to stand to the west of each test point.

Weather data (relative humidity, atmospheric pressure) for the Athens, Georgia area at the time of each visit was obtained from the Internet site Weather Underground (www.wunderground.com). Air temperature measurements were obtained using an on-site thermometer. The planned PDOP (Positional Dilution of Precision) for the data collection periods was acquired using Trimble GPS planning software and a current almanac, since actual PDOP measurements were unavailable from the GPS receiver studied. Although a direct comparison of planned and actual PDOPs has not been conducted, we assume that the planned PDOPs are lower than the actual because planned PDOPs seem to be determined for ideal conditions, while actual PDOPs take into account that some of the ideal satellites are not used to determine a position due to obstructions (trees). The accuracy of static horizontal positions was reported as a root mean squared error (RMSE):

$$RMSE = \sqrt{\sum_{i}^{n} \frac{(x_i - x_T)^2 + (y_i - y_T)^2}{n}} \qquad (1)$$

Here, n is the total number of observations (position fixes) during a visit to each test point, i is the ith observation during each visit ($i = 1$ to n). In addition, x_i and y_i represent the estimated easting and northing values of the ith observation, respectively, in the UTM, NAD 1983 coordinate system. And, x_T and y_T represent the true easting and northing values of the test point. These average RMSE values for each visit to each test point were used along with the weather conditions in the statistical analysis.

Forest structure variables were obtained through field measurement. Using a staff compass, every live tree greater than 1.37 m tall that was within a horizontal distance of 20 m from the selected GPS test point (number 37) within the Whitehall Forest GPS Test Site was measured. The staff compass was plumbed over GPS test point 37, representing the center of the sample points. The declination of the staff compass was adjusted so that the line between GPS test point 37 and GPS test point 36 was 120^o, when viewed towards the east. The lead author has been using a staff compass regularly in an educational situation for nearly 15 years, and was confident that the azimuth from GPS test point 37 to each tree could be obtained to within 0.25^o. Smaller, minor differences between the azimuths of trees nearly on the same line from GPS test point 37, but not quite 0.25^o apart were estimated to about 0.1^o. The azimuth was measured to the center of each tree facing GPS test point 37. The horizontal distance from GPS test point 37 to each tree was measured to the center of each tree perpendicular to GPS test point 37. The diameter of each tree was measured at 1.37 m above ground on the upper slope side of each tree. The species of each tree was recorded simply as *pine* or *hardwood* (deciduous). Nearly all of the pine trees were loblolly pine, however a few shortleaf pine (*Pinus echinata*) volunteer trees were also measured in the young pine stand. The hardwood trees were composed mainly of small-diameter sweetgum (*Liquidambar styraciflua*), although a few black cherry (*Prunus serotina*), water oak (*Quercus nigra*) and other minor species were measured. From this information, and using the estimated location of each tree (Figure 1), we developed 50 forest structure variables (Table 1) in preparation for determining whether there was an association between these and the average static horizontal position error observed at each temporary test point. Trees within 5 m of each temporary test point were used to compute the forest structure variables.

Table 1: Forest structure variables used in the analysis of static horizontal position accuracy. These involved measurements of live trees, and were summarized as values within 1, 2, 3, 4, and 5 m from each test point.

Total tree count
Total tree basal area
Pine tree count
Pine basal area
Hardwood tree count
Hardwood basal area
Average departure (east-west orientation) of pine trees from each test point†
Average latitude (east-west orientation) of pine trees from each test point†
Average departure (east-west orientation) of hardwood trees from each test point†
Average latitude (east-west orientation) of hardwood trees from each test point†

†These distances were weighted by the diameter of each tree, therefore larger diameter trees had greater influence on these values than smaller diameter trees.

Table 2: Average positional error (RMSE), observed average vector of the error (using average departure and latitude values), and average vector distance.

Test point	Average positional error (m)	Observed average vector (°)	Observed vector distance (m)
1	5.02	237.3	3.93
2	4.59	187.4	2.62
3	3.97	198.1	2.04
4	4.72	236.0	1.86
5	4.89	250.8	3.07
6	5.00	275.9	4.05
7	4.56	169.7	1.40
8	4.38	212.3	1.96
9	4.24	257.7	2.01
10	4.64	284.7	2.80
11	5.58	287.7	4.23
12	4.38	114.4	2.93
13	4.41	113.9	1.31
14	4.32	101.7	0.70
15	4.77	310.0	2.97
16	5.18	313.5	4.16
17	6.13	305.2	5.34
18	5.02	73.2	3.51
19	3.90	37.0	1.74
20	4.59	354.8	2.05
21	4.65	336.6	2.68
22	6.11	335.6	4.79
23	5.55	59.9	3.89
24	4.90	41.4	3.37
25	4.91	13.2	2.98
26	5.81	2.0	4.11
27	5.32	338.9	3.85
28	5.46	19.4	3.75
GPS control point 37	4.46	336.4	1.48

Correlation analyses were performed between the dependent variable values (error) and other variables (PDOP, air temperature, relative humidity, atmospheric pressure, etc.). Pearson's r correlation coefficient was used to measure correlation among the variables. In this study, we also use correlation analysis to determine the strength to which forest structure variables are associated with average positional error, departure (east-west) error, and latitude (north-south) error. Rose diagrams (circular histograms) were then developed to visually assess the association between the direction of error and two of the fifty forest structure values. The magnitude of positional error, expressed as the distance associated with the average departure and latitude, was developed for each of the test points. The average latitude and distance to all trees, pine trees, and hardwood trees within 5 m of each test point was then developed and converted into a vector representing the magnitude of these forest conditions. These were also then weighted by the basal area of each tree to produce vectors representing a weighted magnitude of forest conditions. Correlation analyses using Pearson's r correlation coefficient were then applied to determine whether any association exists between the *magnitude* of positional error and the vectors representing the *amount* of forest conditions within 5 m of each test point. From the average latitude and departure values for each test point we further developed a vector representing the average azimuth (direction) of error. Similar vectors representing the average direction of all trees, pine trees, and hardwood trees were developed. These were also then weighted by the basal area of each tree to produce vectors representing the weighted direction of forest conditions. The vectors (represented

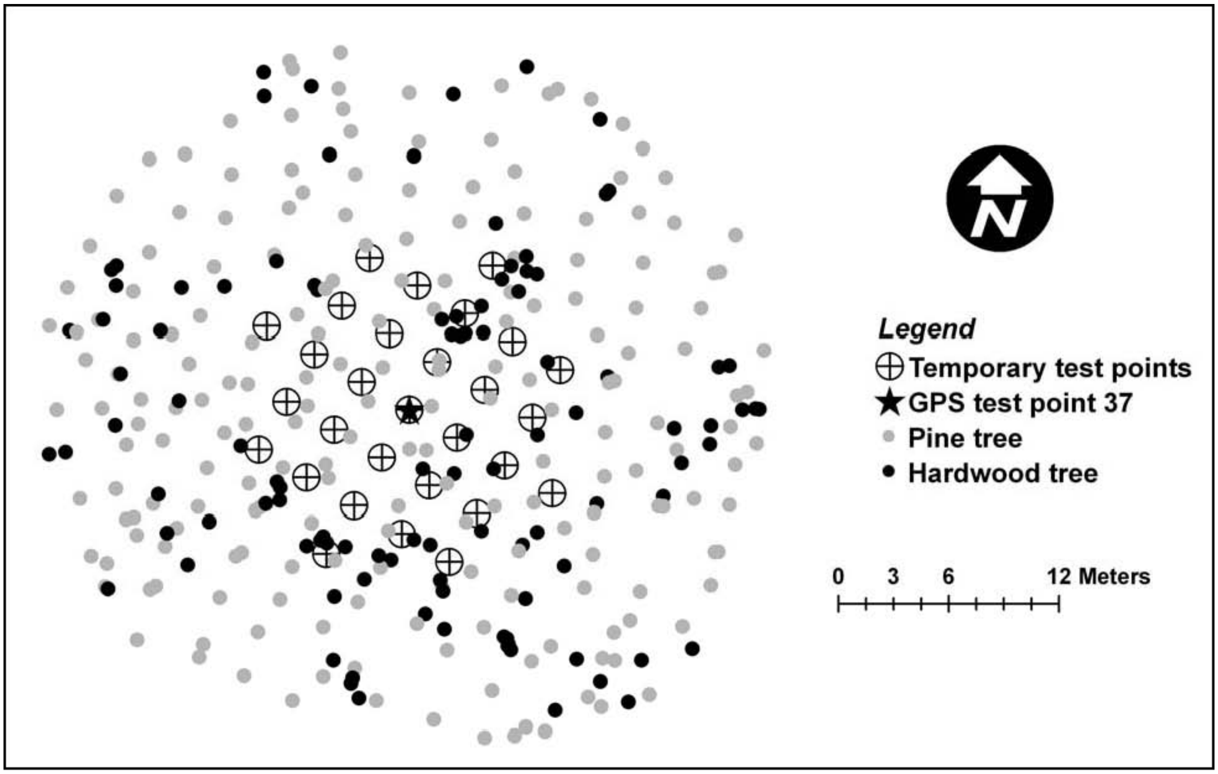

Figure 1: The arrangement of temporary test points, pine trees, and hardwood trees around GPS test point 37 of the Whitehall Forest GPS Test Site.

by azimuth values) were then transformed using the logic below in order to normalize the data:

If (azimuth $\leqslant$ 180°), then transformed azimuth = azimuth / 180°

Else, transformed azimuth = (180° - (azimuth - 180°)) / 180°

When applying this transformation, azimuths representing South (near 180°) are converted to values around 1.0, while azimuths representing North (near 0° or near 360°) are converted to values around 0.0, regardless of which side of North the azimuths lie. Correlation analyses using Pearson's r correlation coefficient were then applied to determine whether any association exists between the *direction* of positional error and the vectors representing the *direction* forest conditions within 5 m of each test point.

3 Results

Over the entire course of the study, the average positional error for all 29 test points was 4.88 m, yet ranged from 3.90 to 6.13 m depending on the test point (Table 2). In examining each individual day of the study period, we found that the average error of 10 position fixes ranged from 0.17 to 22.70 m. The average positional error determined for each day, for each test point (from the collection of ten position fixes captured at each test point on each day) was used to determine whether these were correlated with environmental variables and planned PDOP. Of the environmental variables measured, none had a significant effect on positional error. Mean error values were very weakly positively correlated with relative humidity (0.114) and very weakly negatively correlated with air temperature (-0.161). Barometric pressure and planned PDOP of the NAVSTAR satellite configuration had even less association with observed error in static horizontal positions.

The average positional error from each test point over the period of study (from the collection of ten position fixes captured at each test point during 30 visits) was used to determine whether these were correlated with a set of 50 forest structure variables. As an example of the data employed, Figure 2 illustrates the average position determined with each visit to a test point, the actual test point position, and the neighboring live trees. In the initial assessment, the average departure of the positional error (east-west error) and the average latitude of the positional error (north-south error) were used along with the distance representing the average straight-line error. Of the forest structure variables, two (hardwood basal area within 4 m and hardwood basal within 5 m) showed moderate positive correlation with average positional error (Table 3). Hardwood tree count within 4 m and within 5 m also had low to moderate positive correlation with average positional error. This suggests that

Table 3: Correlation between measures of positional error and select forest structure variables.

Variable	Average positional error (m)	Departure error (m)	Latitude error (m)
Total tree count, 5 m	0.480	-0.013	0.324
Total basal area, 4 m	-0.116	0.488	0.068
Pine tree count, 4 m	-0.153	0.580	-0.065
Pine tree count, 5 m	0.102	0.593	-0.040
Pine basal area, 4 m	-0.167	0.524	0.033
Pine basal area, 5 m	0.129	0.476	0.021
Hardwood tree count, 4 m	0.445	-0.309	0.215
Hardwood tree count, 5 m	0.455	-0.293	0.357
Hardwood basal area, 4 m	0.589	-0.574	0.345
Hardwood basal area, 5 m	0.557	-0.564	0.478

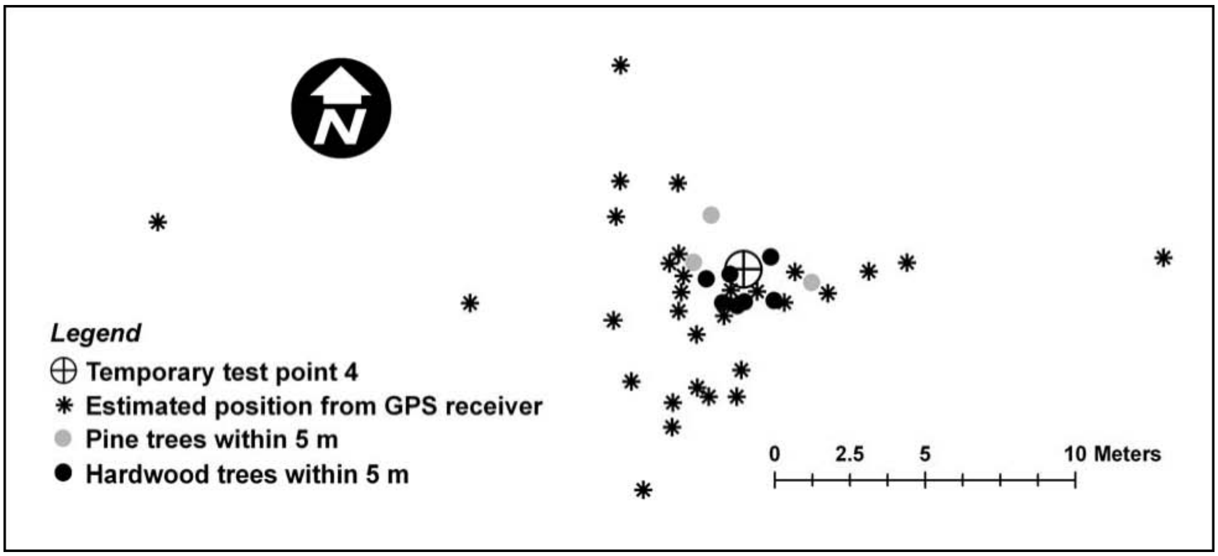

Figure 2: The arrangement of determined positions of temporary test point 4 in relationship with the true position of temporary test point 4 and nearby pine and hardwood trees.

as these structural variables increased in magnitude, average positional error tended to increase, and as they decreased in magnitude, average positional error tended to decrease. Interestingly, the correlation analysis suggested that these variables were low to moderately negatively correlated with departure error, suggesting that as these structural variables increased in magnitude, departure error tended to be toward the west. As they decreased in magnitude, departure error tended to be toward the east. These variables were also low to moderately positively correlated with latitude error, suggesting that as these structural variables increased in magnitude, departure error tended to be toward the north. As they decreased in magnitude, latitude error tended to be toward the south. Pine tree count and pine basal area (both 4 m and 5 m distances), along with total tree basal area within 4 m of a test point, were moderately positively correlated with departure (east-west) error. This suggests that as these structural variables increased in magnitude, departure error tended to be toward the east.

The orientation of the vector that described the average positional error varied considerably for the 29 test points (Table 2). The observed vector distance, or magnitude of this error, using the average departure and latitude values for each of the 30 samples collected, ranged from 0.70 to 5.34 m, and averaged 2.95 m. The length of this vector was related to both the magnitude of the error and the direction of the error. In some respects, a large value of the observed vector distance is analogous to a small variance in a linear variable (Jones 2006a), however large individual errors might have significant influence the size of the observed vector distance. The observed vector distance values are always smaller than the average positional error (RMSE), because the average positional error does not take into account the *direction of error*. For example, assume two samples produced RMSE values of 4.0 m and 3.0 m. The average positional error of these is 3.5 m. However, if one of these was oriented to the north of a sample point, and one was oriented to the south, the observed vector distance would be 0.5 m, and would also be oriented to the north.

To further illustrate some of the issues concerning the orientation of error and the orientation of forest conditions, Figure 3 provides a glimpse of four of the test points, their average error, and total tree count and hardwood tree count within 5 m of each test point. For example, results from test point 8 suggest that the static horizontal error from 30 visits was concentrated to the south of the test point (Figure 3, part a). Interestingly, live trees were concentrated to the northwest and northeast of the test point (Figure 3, parts b and c). Results from test point 12 suggest that static horizontal error was concentrated to the southeast of the test point (Figure 3, part d), while live trees were concentrated to the northeast of the test point (Figure 3, parts e and f). Interestingly, results from test point 22 suggest that static horizontal error was concentrated to the northwest of the test point (Figure 3, part g), while live trees were perhaps more concentrated to the south of the test point (Figure 3, part h). Similarly, results from test point 24 suggest that static horizontal error was concentrated to the northeast of the test point (Figure 3, part j), while live trees were perhaps more concentrated to the south of the test point (Figure 3, parts k and l). These results seem to indicate a trend where the determined position from the GPS receiver was negatively attracted to the location of the trees within 5 m of each test point. However, there are many combinations of forest parameters that might be explored to further elucidate these trends, and the trends were not entirely evident in some cases. Admittedly, more effort can be extended to an exploration of these relationships using methods described by Jones (2006a, 2006b) and others. We leave this as an open area of research for others to pursue since some of the directional analysis concepts described in previous work have not yet been applied to the type of forestry data provided here.

In examining the magnitude of error observed in conjunction with the average distance to trees around each test point (Table 4), we found significant negative correlation with the number of hardwood trees and with the basal area of hardwood trees. This suggests that GPS error decreased as the average distance (simple average or weighted by basal area) increased from each test point, regardless of the orientation of these trees with respect to the test point. When the direction of average GPS error was compared to the average direction to the trees around each test point, a weak negative correlation (-0.345) between the average vector representing the direction to hardwood trees and the average direction of GPS error was observed. These results lend credence to the notion that the error observed with the GPS receiver tested may be influenced by the number and orientation of hardwood trees within a young pine stand that are situated around a test point where static horizontal positions are collected.

Table 4: Correlation (Pearson's r) between measures of direction (azimuth) and magnitude (meters) of positional error and direction (azimuth) and magnitude (meters) of tree locations.

Variable	Plot Radius (m)	Average magnitude of error	Average direction of error
Total tree count	5	-0.283	-0.167
Total basal area	5	0.261	0.015
Pine tree count	5	-0.065	0.229
Pine basal area	5	0.259	0.014
Hardwood tree count	5	-0.557†	-0.345
Hardwood basal area	5	-0.430†	-0.072

$^{\dagger}p < 0.05$; $^{\ddagger}p < 0.01$

4 Discussion

When employing a recreation-grade GPS receiver in a dense young pine forest in the southern United States, we found that most forest structure variables were weakly correlated (0.400 to -0.400) with the three measures of error (average straight-line error [RMSE]), average departure error [east-west], and average latitude error [north-south]). In fact, the highest correlation values were found for forest structure variables within 4 or 5 m of each test point, rather than 1-3 m. This is perhaps because while some vegetation was situated within 1-3 m of a test point, more vegetation was situated within 4-5 m. It should be noted, that the test point locations were not affected (nor adjusted) as a result of the vegetation found in the sample area. One test point was in fact mere centimeters from two different trees, and others were situated near or within clumps of small hardwood trees.

Of direct interest to our objective, the orientation (weighted departure or latitude) of some of the vegetation within 5 m of each test point did seem to influence the magnitude (size) of positional error observed. While correlation analysis was used to assess the association between vectors representing the magnitude and direction of both GPS error and vegetation location, further analysis using methods described by Jones (2006a, 2006b) to explore inferences on the observed vector mean (azimuth) and observed vector distance associated with

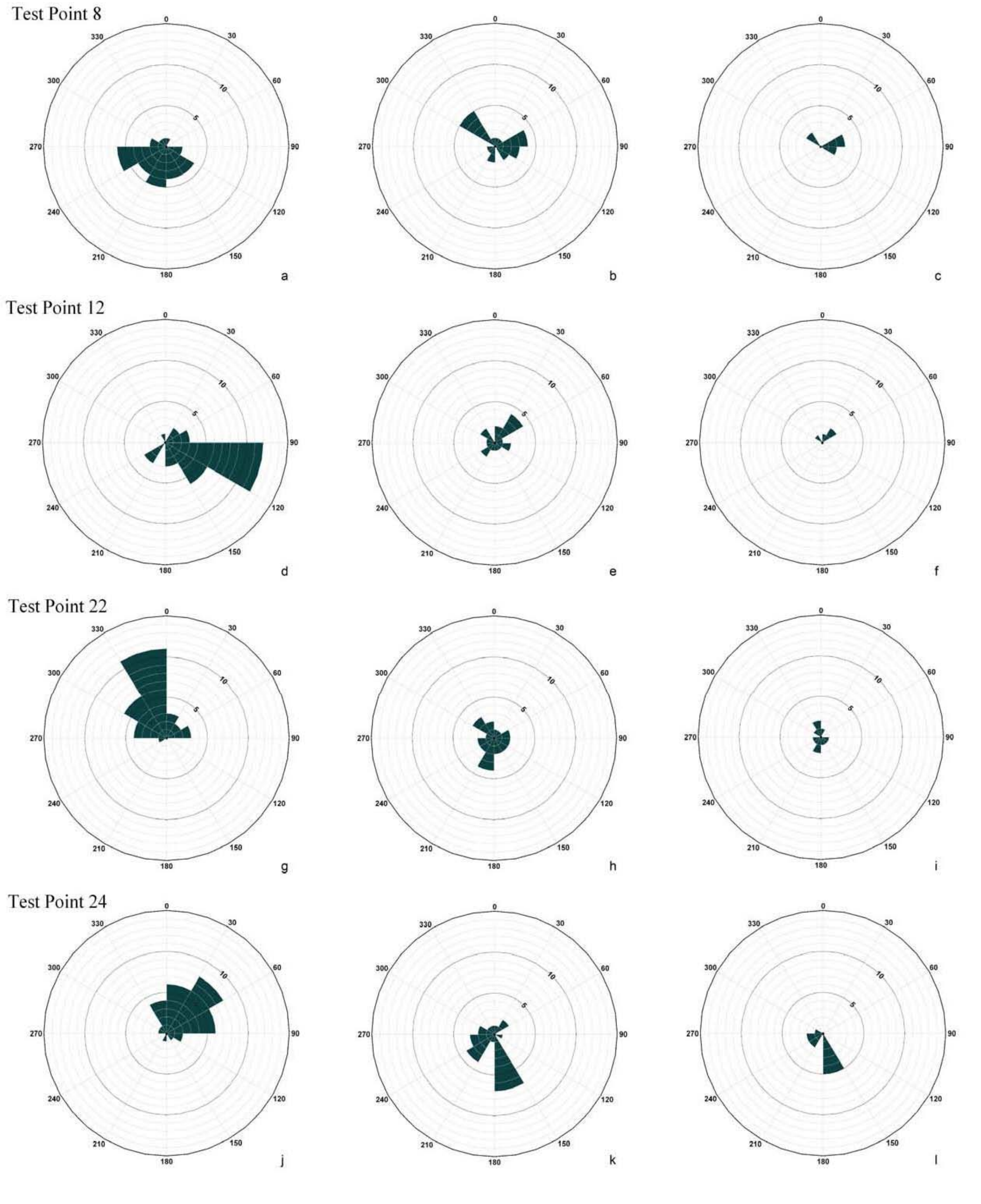

Figure 3: Rose diagrams that illustrate the orientation of positional error (a, d, g, j), live trees (b, e, h, k), and live hardwood trees (c, f, i, l) in relation to four different sample points, as represented by sets a-c, d-f, g-i, and j-l.

static horizontal position accuracy may be necessary to determine more precisely the causes of error. These include exploration of the correlation between two variables that are described in a circular manner. Figure 3 illustrated this data graphically using a rose diagram, which was essentially a frequency distribution of error vectors and tree locations in 30^o increments. The association between these types of data could employ canonical correlation coefficients, T-monotone or T-linear associations, resampling, and a deconstruction of the azimuthal variable into components such as the departure and latitudes described here. However, these analyses are beyond the scope of this exploratory study and left for others to pursue.

As with recent studies of GPS receivers in forested settings (Bettinger and Fei 2010, Ransom et al. 2010), in this study there was very little association between static horizontal position accuracy, environmental variables, and planned PDOP. It therefore seems safe to say that lower atmospheric conditions that are typically measured (air temperature, relative humidity, barometric pressure) have little effect on some consumer-grade receiver accuracy in forested conditions, at least within typical ranges of values observed in the southern United States. From the analyses provided here is also seems safe to say that within young pine forests, the density and distribution of hardwood volunteers may affect the quality of GPS data collected. However, in studies such as these, where control over data methods is necessary, the full range of potential factors influencing data quality have not been addressed. Therefore, the position of the data collector with respect to test points, and the use of near-real time augmentation (i.e., WAAS) may need further exploration.

5 Conclusions

We hypothesized that static horizontal position accuracy of a consumer-grade GPS receiver would not be influenced by environmental conditions or satellite geometry, and as in previous studies, we found that we could not reject this hypothesis. However, we found evidence to conclude that the density and arrangement of live deciduous (hardwood) trees within a young pine forest may have some influence on position quality. Our results also indicate that there was a moderate correlation between average static horizontal position error and a few measures of forest structure within 5 m of a sampling point. As suggested, within a young pine forest, hardwood basal area and hardwood tree count seemed to be the most important of these variables. Interestingly, forest vegetation closer than 4 m from a test point did not seem to influence static horizontal position accuracy. Further, using rose diagrams that illustrate the direction of error and the direction of forest vegetation with respect to the location of a test point, we observed some negative attraction between local forest conditions and determined positions.

These results are important for both static and dynamic use of GPS equipment in forests with a high density of trees. It is presumed that signals deflecting from tree boles or passing through tree canopies may have (a) multipath problems or (b) lower signal to noise ratios. With lower-grade GPS equipment, provisions (algorithms, advanced antennas, etc.) to remove lower-quality signals from consideration may be lacking, and these may likely be used to describe the location and shape of landscape features. Many questions remain, however, such as the density of trees above which these issues matter, the error expected when working within or around a dense forest, and how one may be able to correct for problems encountered in these situations. However, the error contained in data and information developed through the use of GPS technology can have significant ramifications for forest resource managers. For example, the boundaries of forest areas are now often mapped using GPS receivers, and the area determined from these efforts is often used to determine wood volume or value. Further, areas, volumes, and values are often incorporated directly into contracts for silvicultural operations. Should positional information collected with GPS equipment be used for research purposes, the error inherent may be propagated forward in subsequent spatial analyses, perhaps rendering the conclusions drawn somewhat tenuous (depending on the type of analysis performed). Therefore, further investigation into the influence of the juxtaposition of trees on static horizontal position accuracy may be necessary.

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