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Dynamic accuracy of recreation-grade GPS receivers in oak-hickory forests

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The study, using 20 individual instruments of one model of recreational-grade Global Positioning Systems (GPS) receiver, was conducted in a mature predominantly deciduous forest in the southern United States. The true area was delineated from the eight test points that were very accurately located from monuments using survey-grade instrument and protocols, within the Whitehall Forest GPS Test Site in northeast Georgia. These same eight test points were used as controls during the dynamic horizontal accuracy assessments of GPS technology conducted within the forest. The test points are very precise compared with recent published literature. Our hypotheses were that the areas determined with the 20 receivers were not significantly different from the true areas, and the percentage of the area of agreement and the variation of the vertices around the true boundary were not different in winter and summer seasons. Also, based on the distribution of the vertices around the true boundary, we conducted simulations for larger areas. The average area of agreement was ∼93 per cent during the winter season, and ∼84 per cent during the summer season. The variation in sample areas was also greater for data collected during the summer, and data from the winter had higher association as measured by area of agreement with the true study area than data from the summer. A ranking of receivers by average area during each season did not reveal significant problems within the set of receivers tested. In conclusion, data collected during each season were not significantly different. Given the distribution of vertices around the true boundary of the study area, simulations of larger land areas revealed that there would be a 2 per cent or less error for mature, deciduous forests of greater than ∼25 ha in size in both winter and summer seasons.

Introduction

For forestry and natural resource management purposes, Global Navigation Satellite Systems help address a number of navigational, positioning and mapping needs. In many areas of the world, these systems are referred to as Global Positioning Systems (GPS). Satellite navigation and positioning systems are based on electromagnetic energy emitted by satellites and received by devices often located inside an automobile or airplane, attached to an animal, or held within a person's hand (Bettinger and Merry, 2011). Satellite positioning systems can often provide highly accurate locational information when compared with traditional navigation and mapping techniques (Naesset and Jonmeister, 2002; Bettinger and Fei, 2010). However, accuracy and precision under a forest canopy are often very low when compared with similar measures in open areas (Rodriquez-Perez *et al*., 2006, 2007). This is important because resource managers frequently use the information obtained to delineate land boundaries, inventory plots, roads and other features of interest. The spatial accuracy of the devices (receivers) should be of high interest, as the application of GPS technology within a forested environment is perhaps one of the most demanding uses due to masking and blocking effects caused by trees (Pirti, 2005). Therefore, advances in GPS technology require continual research and review for their application under tree canopies. Research in this area has thus evolved from purely observational studies conducted a decade ago to a blend of observational and hypothesis-driven studies today.

GPS receivers can be divided into three general classes: survey-grade, mapping-grade and consumer-grade (or recreational-grade). Survey-grade GPS receivers are generally able to determine locations within 1-cm horizontal position accuracy in open areas and within 1-m accuracy in forested landscapes (Wing, 2008). The time required to use them, the cost (∼10 000–25 000 U.S. dollars (USD)) and the size of these units make them inappropriate for fieldwork in a forested landscape (Bettinger and Fei, 2010). Mapping-grade GPS receivers are generally capable of providing accuracy within 1 m in open areas, and 2- to 5-m accuracy under forest canopies (Ransom *et al*., 2010). These receivers are frequently used in forest management and have a price range of 1000 to 5000 USD. Recreation-grade receivers provide the least accurate positional information, generally between 5 and 10 m depending on environmental conditions (Wing, 2011). The cost range of recreational-grade GPS receivers is ∼100–600 USD. The cost of data collection and the desired accuracy levels of referenced positions should be taken into account when choosing a GPS receiver (Wing *et al*., 2005; Bettinger and Fei, 2010).

It has been shown that precision and accuracy of data collected with GPS receivers decrease when used in forested landscapes (Deckert and Bolstad, 1996; Naesset and Jonmeister, 2002; Rodriquez-Perez *et al*. 2006, 2007; Danskin *et al*., 2009) because GPS uses microwave signals, and forest vegetation and topography might interfere with the satellite signals (Veal *et al*., 2001). The highest accuracy in these types of environments requires using expensive and sophisticated equipment. However, some users hesitate to employ the highest accuracy equipment in forested areas because they fear they might damage equipment that is expensive to replace (Wing, 2011). Recreational-grade receivers have thus become popular for a variety of natural resource applications in forested environments because of their affordable prices and their ease of use. While often a concern, measurement accuracy of these receivers might be adequate depending upon the goals and applications of a project (Wing, 2011).

The techniques employed for the assessment of GPS technology are well-established in the forestry field (Bettinger and Merry, 2011). GPS accuracy (often used interchangeably with 'error') is highly important for mapping, record-keeping and research purposes, and many (e.g. McRoberts, 2010) have cautioned users on the potential pitfalls of using the information. The two main areas of concern for natural resource management professionals include static horizontal position accuracy (for points) and dynamic (kinematic) accuracy (for areas). A number of studies have recently illustrated the static horizontal accuracy of recreation-based receivers (e.g. Wing *et al*., 2005; Wing, 2008; Anderson *et al*., 2009; Wing, 2009; Bettinger and Fei, 2010; Bettinger and Merry, 2012b), yet assessments on the dynamic accuracy of recreation-grade receivers have been lacking. Most studies concerning GPS accuracy involve assessments of commercially available equipment applied to forest conditions in manners typical of common field data collection processes. For dynamic accuracy studies, GPS accuracy and precision would ideally be compared against an independent control (Tachiki *et al*., 2005). However, at times the comparison has been reported only against the mean position determined from the epochs (waypoints, position fixes) recorded by other GPS receivers positioned at the same place (Taylor *et al*., 2004), against other benchmarks (Holden *et al*., 2001; Veal *et al*., 2001; Buerkert and Schlecht, 2009), or no control was necessary for the purposes of the associated studies (Zenner *et al*., 2007).

In a dynamic or kinematic mode, GPS has been used to track the movement of forest machines (Veal *et al*. 2001; Zenner *et al*., 2007). Liu and Brantigan (1995) evaluated whether GPS technology was able to achieve more accurate dynamically collected data than traditional methods (compass and chain) in closed forest stands. A number of advanced methods have also been tested in order to seek improvements to GPS accuracy levels, such as the correction of satellite orbit and clock errors, the post-processing of data using filters and modelling and the mitigation of other external effects (Beran *et al*., 2007). Unfortunately, these latter areas of concern are rarely addressed by natural resource management professionals due to the added time and cost of application. GPS technology is also often used to monitor the locations of wildlife of concern (e.g. Dussault *et al*., 2001; Gervasi *et al*., 2006). Therefore, the value in understanding the dynamic accuracy of GPS receivers lies in end uses of the information. For example, Kiser *et al*. (2005) once suggested that GPS could be of value in the design of timber sale areas, replacing other field methods that are based on magnetic fields or control points. In many cases in the management of forests, the edges (boundary) of an area described by GPS-collected data, and the subsequent area that is determined, may be used directly in contracts and research assessments.

As a result of these concerns, increased attention to the dynamic accuracy of new technology is essential. We, therefore, designed a study to assess the dynamic accuracy of a single model of recreation-grade receiver, the Garmin 450t, (Garmin International Inc. 2013), within a forested condition, across two seasons of the year (winter and summer). Receivers were supplied by the University of Georgia's School of Forestry and Natural Resources. The receivers were purchased not because of their cost (400 USD each) or their size, but because of their user-friendliness with respect to classes taught at the university.

Our objectives were to assess the area of agreement with a relatively small well-defined closed area, to determine the variation of waypoints around true boundaries and to determine whether significant differences were evident among the two seasons of the year. The following hypotheses were tested to evaluate the accuracy of this model of recreational-grade GPS receivers:

H1: difference in areas estimated by recreational-grade GPS units from the true area is the same whether the GPS data are collected in winter or in summer.

H2: the seasons do not cause differences in the percentage of vertices within 1-m bands (1 m, 2 m, 3 m, etc.) of the true area boundary regardless of the season.

H3: the area of agreement between the true area and the sample areas (after an intersect process) is the same in winter as in summer.

In addition to these hypotheses, we simulated larger areas of different sizes (1 to 49 ha). It helped us to understand how the effects of the observed error from our small study area might impact area measurements when applied to larger land areas.

Methods

We developed a 0.90-ha (2.22 acres) test area in a mature deciduous (oak-hickory) forest that was 60–70 years old with 26.2 m^2 ha^{-1} basal area and 421.7 stems ha^{-1}. Ideally, for a dynamic accuracy study, independent control would arise from a formal survey of a closed area (Bettinger and Merry, 2011).

The true size of the study area was determined using a closed area that was defined by the coordinates of eight GPS test points located on the Whitehall Forest GPS Test Site near Athens, Georgia (USA) (Figure 1). In developing the Whitehall Forest GPS Test Site in 2004, positions of a set of nearby established survey monuments were determined using a survey-grade GPS receiver (Ashtech Locus GPS) according to protocols (static data, 4 h of data collection, etc.) that would allow the determined positions to be considered and accepted as National Spatial Reference System (NSRS) positions. The positions of the monuments were processed using the U.S. Department of Commerce, National Oceanic and Atmospheric Administration's Online Positioning User Service (OPUS) (www.ngs.noaa.gov/OPUS). The positional precision of these monuments was <2 cm. The closed traverse network that represents the Whitehall Forest GPS Test Site corners was then established by registered surveyors using a Topcon GTS-211D instrument and the NSRS monuments as a base. The closure of the points within the Test Site (as represented by a closed traverse connecting the points) was estimated to be 1/92 137. Given this resource, and for this particular study, we then very carefully delineated a straight line (using string) between the Test Site corners in order to provide the best indication of the position of the perimeter (boundary) of the area as one might expect in

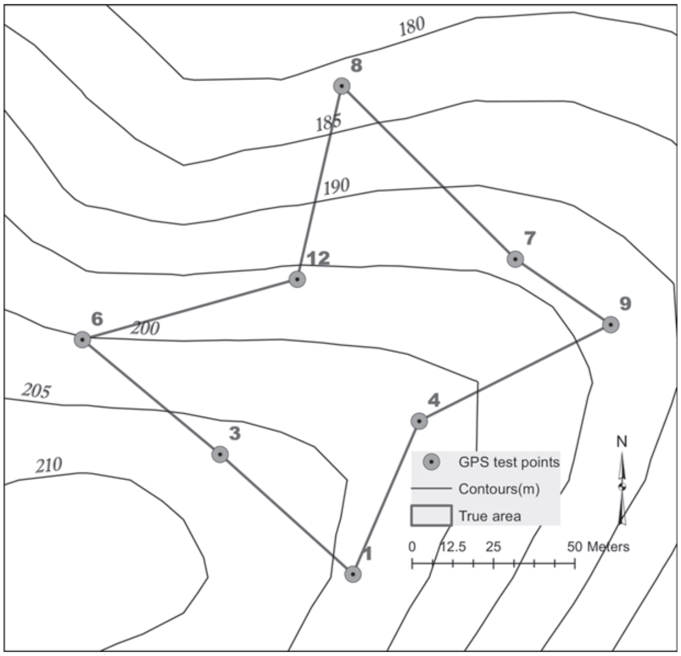

Figure 1 A map of the study of the area and the Whitehall Forest GPS Test Site points used in this study.

field conditions. We, therefore, consider the closed area as a highly accurate model around which the recreation-grade GPS equipment could be tested.

In a dynamic horizontal position analysis, data are collected as a field-based receiver travels around a fixed course (an area) or along a fixed line. It is therefore important to maintain the receiver's antenna as close to the boundary of the area when waypoints or vertices are being collected because even tree position can affect positional accuracy (Bettinger and Merry, 2012b). If this is not the case, an unknown amount of error (deviations from the boundary or the line) may be inherent in the sample simply due to a loss of control. Our effort for controlling and understanding the true boundary of the study area is new and unique to the literature published thus far regarding the accuracy of dynamically collected GPS data in a forested environment.

The data were collected both in winter (leaf-off) and in summer (leaf-on) with 20 different Garmin Oregon® 450t recreational-grade GPS receivers that only utilized satellites from the United States Navigation Satellite Timing and Ranging System (NAVSTAR) GPS program. These GPS receivers were considered state-of-the-art for recreation-grade equipment at the time of the study. Each receiver was used to determine the test area boundary, once per day. The availability of the researchers and the likelihood of non-rainy days were taken into account to determine the time for leaf-off (12–13 January 2013) and leaf-on (5–6 June 2013) data collection efforts. Each receiver was randomly chosen and used twice during each season; thus, 40 samples of the test area were collected during each season. Before starting to collect data, a warm-up period (3–5 min) was required to ensure that each receiver was tracking a sufficient number of satellites. In collecting positional information regarding the boundary of the study area, the researchers collected waypoints (vertices of the boundary) at ~10-m intervals, holding the GPS receiver directly over the string during data collection process.

The dynamically collected GPS data were downloaded to a personal computer using Minnesota DNRGPS software (Minnesota Department of Natural Resources, 2012). The data were saved in shapefile format to be used in conjunction with a geographic information system (GIS) (ArcGIS 10.0, ESRI 2013). The average number of the vertices for the closed area was 50.78 in winter and 52.78 in summer. In only one case was a waypoint (boundary vertex) manipulated. In this case, the very first vertex of one sample area was obviously well away (50+ m) from the actual starting position, whereas the other vertices were adequately positioned. We can think of no reason for this anomaly; thus, this vertex was removed from the sample. Using the data collected, three measures were reported: difference in areas estimated by the recreational-grade GPS units from the true area, per cent of vertices within *x* metres of the true boundary (proximity analysis) and area of agreement (after intersecting or overlapping sample areas with the true area). To calculate the difference in area, the closed area determined with each visit during the two different seasons, these were compared with true area.

$$\text{Difference in area} = \text{true area} - \text{sample area} \qquad (1)$$

Through a proximity analysis conducted in GIS, buffers were created using the 'generate near table' function, which is a tool in ArcGIS. This was used to calculate the nearest distance of every point to the study area boundary line. This process helped us understand the percentage of vertices from each sample area that were within 1-m intervals around the true boundary, up to 4 m (Figure 2). The final class included the percentage of vertices 4+ m from the true boundary line.

$$\text{Percentage of the vertices} = \left(\frac{\text{number of the vertices within certain distance}}{\text{total points}}\right) \times 100$$

To evaluate the area of agreement, sample areas and the true area were overlaid (intersected) in ArcGIS to determine the area of agreement between the true area and the sample areas. First, data were imported into ArcGIS 10.0 and converted to an area by connecting the waypoints. Then, the true area was intersected (an overlay process) with each of the samples collected during the different seasons (Figure 3) to determine the area of agreement. The formula below was then used to determine area of agreement.

$$\text{Area of agreement (\%)} = \left(\frac{\text{overlapping area}}{\text{true area}}\right) \times 100$$

To examine the accuracy of the GPS receiver, the normality of the data was assessed to decide which statistical tests need to be used (parametric or non-parametric). Based on the results of this assessment, we determined that the data in general were not normally distributed, which is very common among GPS studies. Thus, the Mann–Whitney non-parametric test within Minitab 16 software (Minitab Inc. 2013) for independent samples collected in winter and summer was used to test the differences between 40 samples collected in each season. As noted earlier, the hypotheses were (1) that the difference in areas was not significantly different between seasons, (2) that the area of agreement between the sample areas and the true area was not significantly different between seasons and (3) that the dispersion of the vertices around the true boundary was not significantly different between seasons.

Recreational-grade receivers are frequently used for natural resource applications. In this study, we were able to evaluate only one recreational-grade receiver within the small test area due to the effort required. However, most of the users in the natural resources field are interested in how error in using the technology relates to larger-sized areas. Hence, after developing information regarding the distribution of observed, field-collected vertices around the true boundary of the study area, simulations of larger areas were conducted. The proximity analysis results of the summer season (representing a worse case than the winter season because leaves affect signals) were used in the development of simulated square areas that were 1, 2, 4, 9, 16, 25, 36 and 49 ha in size. For every 10 m of boundary distance, a random number was drawn and compared with the probability of a vertex falling with the 1-m bands around the true line (up to 5 m). A second random number was then drawn to estimate where the simulated vertex

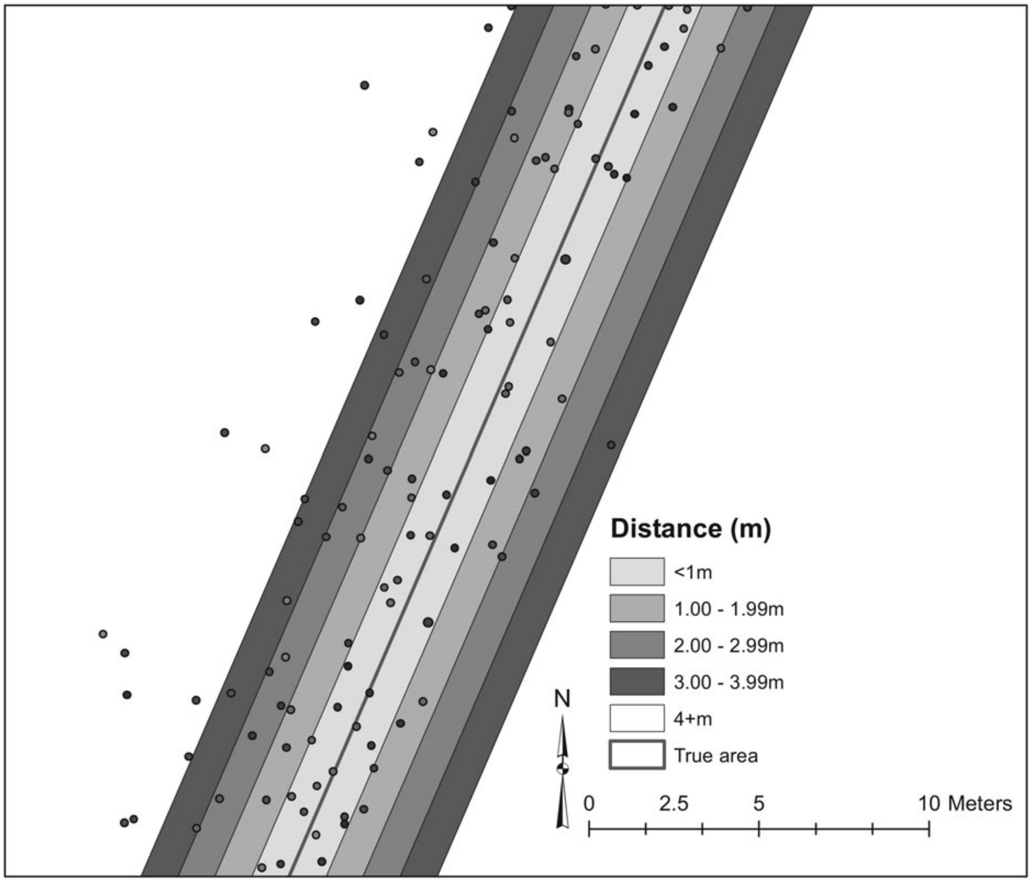

Figure 2 An example of vertices within 1-m buffers around true area with 40 samples in winter.

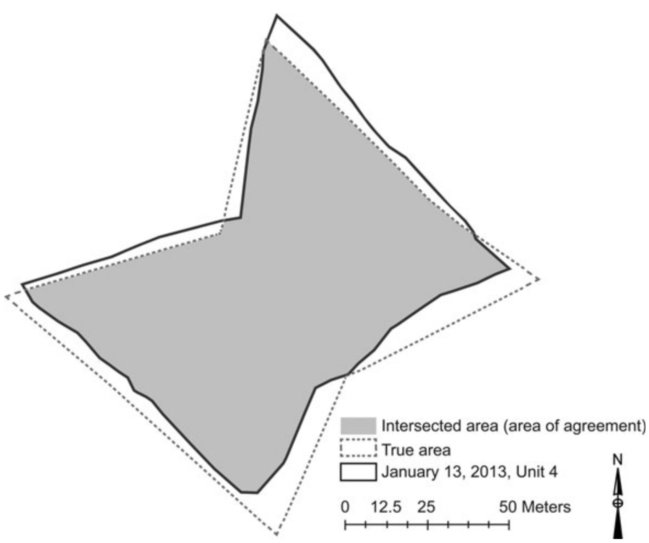

Figure 3 An example of overlay of one sample area on top of the true area.

would lie within the 1-m band assuming a normal distribution of distances within each band. Five simulations were developed for each of the square areas in order to represent errors outside true boundary line, and five simulations were generated for each of the square areas in order to represent errors inside of the true boundary line. These were considered worst-case scenarios, suggesting that the incorrect vertices were always either inside or outside the true boundary, when in fact they may oscillate back and forth over the true line. In any event, these simulations were meant to help us understand the effects of the observed error (from the small study area) when applied to larger land areas.

Results

As we suspected, the sample ($n = 40$) average of closed areas collected using the recreation-grade GPS receiver was closer to the true area during the winter season, when the trees in the study area were devoid of leaves (Table 1). Interestingly, the sample average in both winter and summer was lower than the true area. The summer average area was only ~91 per cent of the true area, whereas the winter average area was ~97 per cent. The standard deviation of sample areas indicates that there was more variation in the summer as well, even though the coefficient of variation of areas during this season was only ~6.1 per cent, which was about twice the coefficient of variation observed in the winter season. The range of the sample areas during the leaf-off season was 0.82–0.93 ha, whereas it was 0.67–0.98 ha during the leaf-on season. When the sample areas were intersected with the true area, the average area of agreement was 92.6 per cent in the winter season, and 84.2 per cent in the summer season. Positional issues related to the vertices that represent the boundary were much more evident in the summer season. When the percentage of vertices within 1-m bands around the true boundary line was assessed, there seemed to be only minor differences among the seasons. However, only the average percentage of vertices within 1.00–1.99 m and 3.00–3.99 m seemed to show large differences among the seasons (Table 1). This analysis did not take into account the direction of error (inside or outside the true area).

Table 1 Results from dynamic study of Garmin Oregon® 450t GPS receiver

	Winter	Summer
True area (ha)	0.90	0.90
Sample average area (ha)	0.88	0.82
Standard deviation of the sample areas (ha)	0.03	0.05
Range of the sample areas		
Smallest area (ha)	0.82	0.67
Largest area (ha)	0.93	0.98
Average area of agreement (%)	92.6	84.2
Average number of the vertices within <1.00 m of the true line (%)	27.4	27.5
Average number of the vertices within 1.00–1.99 m of the true line (%)	25.3	19.6
Average number of the vertices within 2.00–2.99 m of the true line (%)	17.1	17.7
Average number of the vertices within 3.00–3.99 m of the true line (%)	12.1	15.7
Average number of the vertices within 4.01+m of the true line (%)	18.1	19.6

Table 2 Ranking of each Garmin Oregon® 450t GPS receiver after averaging the areas determined during each season

Receiver number	Leaf-on season average area (ha)	Ranking	Leaf-off season average area (ha)	Receiver number
10	0.77	1	0.85	20
16	0.83	2	0.85	4
14	0.83	3	0.85	13
1	0.84	4	0.86	17
6	0.84	5	0.86	16
8	0.85	6	0.86	7
4	0.86	7	0.87	14
12	0.86	8	0.87	9
2	0.87	9	0.87	10
18	0.87	10	0.87	6
17	0.89	11	0.87	12
11	0.89	12	0.88	11
20	0.90	13	0.88	3
7	0.90	14	0.88	5
3	0.90	15	0.89	1
15	0.91	16	0.89	18
5	0.91	17	0.89	15
13	0.91	18	0.90	19
9	0.93	19	0.90	2
19	0.94	20	0.91	8

With multiple receivers, we were able to rank the average performance of each when used in winter and spring. The results from ranking of each Garmin Oregon® 450t GPS receiver after averaging show that with the exception of one, in general receivers did not share the same ranking. Receiver number 11 was ranked as 12th (smallest-to-largest average areas) in both the leaf-off and leaf-on seasons (Table 2). However, one receiver (no. 16) was in the top five of both season's rankings, representing the smaller average areas estimated during the data collection effort. And, two receivers (nos. 15 and 19) were in the bottom five of both season's rankings, representing the larger average areas estimated. The differences in rank were very small (0.1–0.2 ha difference between five or more in the list), and one should bear in mind that these seasonal averages arise from a sample size of two per season for each receiver. Therefore, we were not overly concerned that differences in areas estimated by receivers were due to the receivers themselves.

Three hypotheses were proposed for this research. The results of the Mann–Whitney non-parametric tests (Table 3) indicate that the difference between areas estimated by the recreation-grade GPS receivers and the true area was not significantly different when seasons were compared ($P = 0.77$). Likewise, the percentage of the area of agreement was not significantly different between the seasons ($P = 0.62$). Further, the different seasons did not seem to result in significantly different percentages of vertices within the 1-m bands around the true boundary line. Hence, while the general results (Table 1) hint that there may be differences among the seasons, based on the non-parametric test results (Table 3), no significant differences were observed, and all three hypotheses could not be rejected.

The positional data associated with this study illustrate an interesting situation that has heretofore not been described in the literature. It seems as if the recreation-grade receiver may perform better during dynamic tests of horizontal accuracy than during static tests of horizontal accuracy. The average error of the vertices describing the study area, with respect to the true boundary of the test area, and after accounting for vertices that are both inside the area and outside the area, was ~2.2 m in the winter and 2.3 m in

Table 3 Results of the Mann–Whitney statistical test for significant difference among seasons ($n = 40$ each season)

Hypotheses	Results	*P*-value
Ho: areas not significantly different	Not significantly different	0.77
Ho: percentage areas of agreement are not significantly different	Not significantly different	0.62
Ho: percentage of vertices within <1 m are not significantly different	Not significantly different	0.49
Ho: percentage of vertices within 1.00–1.99 m are not significantly different	Not significantly different	0.42
Ho: percentage of vertices within 2.00–2.99 m are not significantly different	Not significantly different	0.96
Ho: percentage of vertices within 3.00–3.99 m are not significantly different	Not significantly different	0.37
Ho: percentage of vertices beyond 4.00+m are not significantly different	Not significantly different	0.78

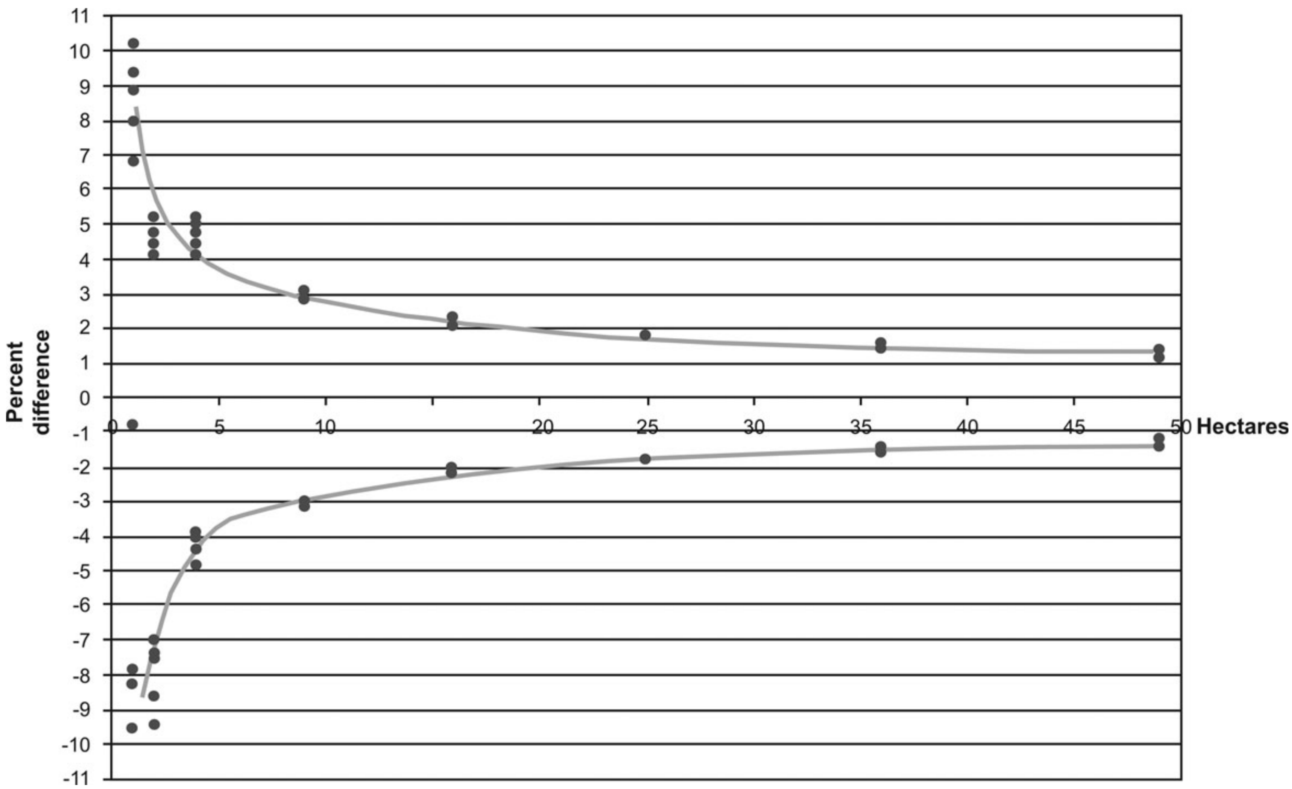

Figure 4 The percentage difference between the true area and simulated areas.

the summer. This of course reflects the perpendicular distance between each vertex and the nearest boundary line and does not take into account larger directional error that may have occurred along (parallel to) the boundary (rather than perpendicular to the boundary). Regardless, recent studies of similar technology (Bettinger and Fei, 2010; Bettinger and Merry, 2012a; Bettinger and Merry, 2012b) suggest that static horizontal positional accuracy should be 4–8 m on average, and recent unpublished static tests of the same technology used in this research suggest that the static error can be perhaps as much as 7–9 m on average.

After simulating larger areas using the distribution of vertices within 1-m bands observed during the summer season, which assumes that the positional error around a true boundary will be similar regardless of the size of the area, our results suggest that the difference in area (compared with the true area) can be as high as 10 per cent for 1-ha forested areas, and as small as ~1.3 per cent for 49-ha areas (Figure 4). At around 9 ha, the simulated error was ~3 per cent, and at ~25 ha, the simulated error in estimated land area was <2 per cent. The results of these simulations were not unexpected. We had assumed that the magnitude of the error in land area estimation would dissipate somewhat as the size of the land area increased; this assumes again that the distribution of error around true boundary lines would not change when land area sizes changed.

Discussion

The accuracy of GPS-collected data when describing land areas and when collected as a person, animal or vehicle moves is of high importance for some fields of natural resource management. In forestry, practitioners want to use new technologies to quickly and effectively determine land areas associated with potential timber sales, natural or man-made impacts (fires, etc.) and critical habitat. Many people look to GPS as a source of this information. Others (e.g. Bettinger and Merry, 2011) have described the differences in GPS technology. In this study, we solely examined recreation-grade GPS receivers, which are typically the least expensive of the vast array of commercially available devices. While the study was limited to one brand and one type of receiver, 20 different receivers were used to assess the quality of data that could be developed. As this is one of the first reported dynamic accuracy tests, and given the tight control we placed on the boundary of the closed area, we feel that the observational results and the tested hypotheses represent a significant contribution to the literature.

Given the physical effort involved in this research, we considered two options: use one receiver multiple times to generate sample areas or use multiple receivers a few times. With one receiver, we run the risk of that one being 'different' from the norm. With multiple receivers, we were able to observe the average performance of each receiver under forest conditions. Thus, we used 20 GPS receivers (all Garmin 450t, and all purchased at the same time) rather than use one GPS receiver to collect measurements for all 80 sample areas (40 collected during each season). We collected information with each of the 20 receivers only four times, and therefore, it was difficult to determine whether any one (or more) of the 20 receivers included measurement error that was statistically and significantly in contrast with the others. However, we evaluated average performance of the each receiver by ranking for both leaf-off and leaf-on season. In general, and given the small sample size, there seemed to be no reason for concern. However, this issue can be important, as in one study of recreation-grade GPS technology, Wing (2009) showed that one may observe differences in the data obtained from receivers of the same vintage and technology.

We surmise that results will vary when other technology are applied to the same forest types with similar tests. Obviously, it would be difficult to conduct and report upon every significant variation in technology, and therefore, we leave open several questions for others to pursue. There have been very few examples of dynamic accuracy assessments of GPS technology employed in forests and reported in the literature, perhaps due to the difficulties in maintaining control of the boundary being mapped. In general, where it is clear and evident in the methodology of other studies, the control was established using mean positions determined from waypoints recorded by other GPS receivers or through means other than an independently established survey. In fact, none of the previous dynamic accuracy studies within forests reported contain the level of control we imposed on the collection of data along a true boundary line, perhaps with the exception of Tachiki *et al*. (2005), though the boundary line control in their case was unclear. Therefore, our study design seems to advance the science in this manner.

One could expand on this research by then applying similar study protocol to the assessment of current mapping-grade GPS technology. Others could also explore the impact of variations in receiver settings on the results obtained. For example, we limited our study to the use of the NAVSTAR GPS constellation of satellites because a typical recreation-grade receiver used in the US can only access signals from this system. However, a number of mapping-grade and survey-grade GPS receivers are now available to capitalize on the signals provided by Russia's GLONASS system, the European Union's GALILEO system and China's COMPASS system. The increase in accuracy and precision that could be achieved using mapping-grade and survey-grade GPS receivers is due to the advanced antenna technology and algorithms employed not only to filter out degraded GPS signals (multipathed or otherwise) but also to optimize the use of satellites from other systems. These advancements in technology typically increase the cost of the equipment, perhaps significantly. A choke-ring antenna, for example, which is designed to mitigate the impact of multipathed signals on determined positions, can cost over 1000 USD, twice the cost of a typical recreation-grade GPS receiver. In areas where Differential Global Positioning Systems capability is available, one could assess whether the near-real-time augmentation that these provide will affect the quality of data collected while moving through a forested environment. In cases where GPS-related research conducted in forested environments is limited due to a lack of funding, well-designed studies such as this provide reliable periodic benchmarks for others to compare against.

Conclusions

We developed a highly controlled dynamic accuracy test of recreation-grade GPS equipment located in an oak-hickory forest of the southeastern United States. The boundary of the test area, which was delineated from eight points accurately located by using survey-grade instruments and protocols, was clear and precise when data were collected, as the line was represented by string extending straight from one corner of our study area to the next. When a waypoint (vertex) was collected, the person collecting the data briefly stopped walking, held the receiver over the string and saved the position. The data were analysed within GIS to determine the size of the sample areas, the area of agreement with the true area and the percentage of vertices that were within 1-m bands around the true boundary. While it seemed that there were general differences between the samples collected in the summer and the samples collected in the winter, statistical tests did not reject the three main hypotheses of the study. Therefore, we cannot state with certainty that vegetative conditions associated with a deciduous forest in winter and in summer had any effect on the area determined, the area of agreement (with the true area) or the distribution of vertices around the true area boundary.

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Conflict of interest statement

None declared.

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