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Using Global Positioning System (GPS) Technology for Tree Marking in a Natural Forest under a Single-Tree Selection System

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Abstract: A single-tree selection system has been widely employed to manage natural forests in Hokkaido, Northern Japan. Tree marking is an essential component of this system; the procedure involves careful selection of trees for harvest according to forest management objectives. Practically speaking, forest managers make tree marking decisions based on their skills gained through training and experiences. While the information on where marked trees are located has traditionally been somewhat difficult to precisely document, recent advancements in global positioning system (GPS) technology could enable managers to pinpoint the geographic location. This paper presents a practical application of GPS technology for tree marking in a single-tree selection forest management system. A total of 1,565 trees were selected and marked for harvest within an area of 29.23 ha at the University of Tokyo Hokkaido Forest. A handheld GPS receiver was used to record the coordinates of all marked trees. To examine positional accuracy, we surveyed the coordinates of 43 marked trees using a closed traverse survey and laser rangefinder with an electronic compass module. Mean positional accuracy of the GPS receiver was 5.7 m, and we observed a variety of harvest intensities over the study site. Results suggest GPS technology is a useful tool

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for improving the precision of forest management activities under a single-tree selection system.

1. Introduction

The single-tree selection system is an uneven-aged silvicultural system under which trees are individually selected for harvest from a large area at regular intervals (Zingg, 1999, Zingg *et al.*, 1999). Under such a system, trees of all diameter classes are mingled over a small area (Schütz, 2006), which is continuously covered; the growing stock changes only in part, and successive regeneration and harvesting are possible (Zingg *et al.*, 1999). In comparison to even-aged silvicultural systems, a relatively steady state of stand structure and ecosystem functions can be maintained over time (O'Hara *et al.*, 2007). Single-tree selection has been widely used in Hokkaido, Northern Japan, since the early 20th century as the preferred option for natural forest management (Yoshida *et al.*, 2006).

In a single-tree selection system, tree marking involves careful selection of trees for harvest based on size, vigor, quality, biodiversity concerns, and wildlife habitat value (Ontario Ministry of Natural Resources, 2004). Selective harvesting produces marketable timber, while also affecting stand regeneration and growth (Owari *et al.*, 2010a). Tree selection is an important technique for successful implementation of the single-tree selection system (Ontario Ministry of Natural Resources, 2004).

Practically speaking, forest managers make tree marking decisions based on their skills gained through training and experiences (Owari *et al.*, 2010a). Each tree is marked and tagged individually, and the species, diameter, and quality grades are recorded. Tracks and approximate positions of marked trees are also recorded on a forest map so loggers can estimate where marked trees are located. Loggers sometimes experience trouble locating marked trees for harvest because precise locations are not known. In the absence of exact positional information, forest managers also face challenges reviewing the accuracy of tree marking and logging operations.

While the information on where marked trees are located has traditionally been somewhat difficult to precisely document, recent advances in global positioning system (GPS) technology (Tsuyuki *et al.*, 2006) could enable managers to pinpoint the geographic location of marked trees. Although GPS has been used in the single-tree selection system at Hokkaido, its use has been limited to traverse surveys for determining harvest unit boundaries (Owari *et al.*, 2009). Before using GPS to map individual tree locations, its applicability and accuracy should be carefully examined.

In this paper, we tested the use of GPS technology for tree marking under a single-tree selection forest management regime. A case study was conducted at the University of Tokyo Hokkaido Forest. We first assessed the positional accuracy of a handheld GPS receiver used for tree marking. Then, the GPS-generated map of marked trees was compared against a conventional method of mapping. Finally, we employed spatial analyses of marked trees by identifying distribution patterns within the case study management unit.

2. Methods

2.1 Study Site

Our study site was sub-compartment 66A of the University of Tokyo (UT) Hokkaido Forest (43° 16-17' N, 142° 28-29' E, 370-400 m a.s.l.). The site was on flat ground, with a total area of 106.27 ha, of which 29.23 ha were classified as a "selection cutting stand". This designation indicates natural regeneration is the desired management objective for the unit, making single-tree selection an appropriate management system (Takahashi, 2001). Technical staff at the UT Hokkaido Forest conducted stand classification in 2007 and 2008. Ground compass surveying (allowable ratio of closure: 1/150) was used to determine unit boundaries. The study site was mostly covered by natural mixed forests, in which the predominant tree species were fir, spruce, linden, birch, oak, and maple. The mean growing stock and tree density (≥ 5 cm DBH) within the study site were 249 m^3 ha^{-1} and 899 trees ha^{-1}, respectively. Coniferous trees accounted for 58% of the growing stock.

Technical staff at the UT Hokkaido Forest conducted tree marking during April and May of 2008 when broadleaves were defoliated. The UT Hokkaido Forest's 12th Management Plan (The Tokyo University Forest in Hokkaido, 2007) specifies a removal rate at 16% of growing stock. The designated removal within the study site was 1,166 m^3 of standing volume (40 m^3/ha); actual removal after tree marking was 1,146 m^3, accounting for 98% of the designated level. A total of 1,565 trees were selected and marked for removal from the study site.

2.2 Data Collection and Analysis

Positions of marked trees were individually recorded as waypoints using a Garmin GPSMAP 60CSx GPS receiver (Garmin Ltd., KS, USA). The GPS receiver is small, handy, and easy to use; these features are suitable for forest inventory (Tsuyuki *et al.*, 2006). It is equipped with a high-sensitivity SiRFstar III GPS chipset (SiRF Technology, Inc., CA, USA), which allows for relatively good GPS signal reception in a forested area (Tsuyuki *et al.*, 2006). Even though differential correction by post-processing is not possible, specifications for the GPSMAP 60CSx claim that its positioning accuracy can be within 5 m after real-time correction using a multi-functional transport satellite-based (MTSAT) satellite augmentation system (MSAS). The GPS receiver was operated by a worker on the marking crew, who also used a caliper to measure the diameter at breast height (DBH). No additional worker was hired exclusively for the GPS measurement. Each position was instantaneously obtained, and we did not average the waypoint over time.

To examine positional accuracy, the true coordinates of 43 marked trees were surveyed with a closed traverse and radial survey using an Impulse 200 laser rangefinder with Mapstar compass module (Laser Technology Inc., CO, USA). A static GPS survey with a ProMark 3 receiver and GNSS Solutions Software (Magellan Navigation, Inc., CA, USA) identified the base point for the traverse survey. The ratios of closure at two courses were 1/6003 and 1/367, respectively. GPS positional errors were calculated using the following equation (Oikawa *et al.*, 2008, Owari *et al.*, 2009):

$$[1] \qquad d = \sqrt{(X_{true} - X)^2 + (Y_{true} - Y)^2}$$

where d is positional error (m), X,Y are measured coordinates, and X_{true},Y_{true} are true coordinates.

To generate a map of marked tree locations, GPS data was converted to the GPS Exchange Format (.gpx) using MapSource software (Garmin Ltd., KS, USA). The “gpx2shp” file converter (Hiraoka, 2010) was used to further convert to the ESRI/Shape Format (.shp). The map projection was first defined as the World Geodetic System 1984 (WGS1984) and later converted to Japan Geodetic Datum 2000 (JGD2000) using ArcGIS 9.3 (ESRI Corp., CA, USA).

The point features of marked trees were used to conduct spatial analyses with ArcGIS 9.3. Trees that intersected harvest unit (those units designated “selection cutting stand”) polygons were extracted using the “select by location” option within ArcMap. The spatial distribution of harvest intensity (trees ha^{-1}) was identified by calculating the point density of marked trees. A cell size of 10 m was used to create the output raster, and the density value was calculated using a circular neighborhood with a radius of 17.84 m.

3. Results

3.1 Positioning Accuracy

Figure 1 shows the frequency distribution of GPS positional error for all 43 measurements. We observed a mono-modal distribution, with a mode of 2–4 m (n = 16). The mean positional accuracy and standard deviation were 5.7 m and 4.0 m, respectively. About half of the measurements (n = 20) had a positional error less than 4 m, whereas seven measurements (16%) had a positional accuracy greater than or equal to 10 m.

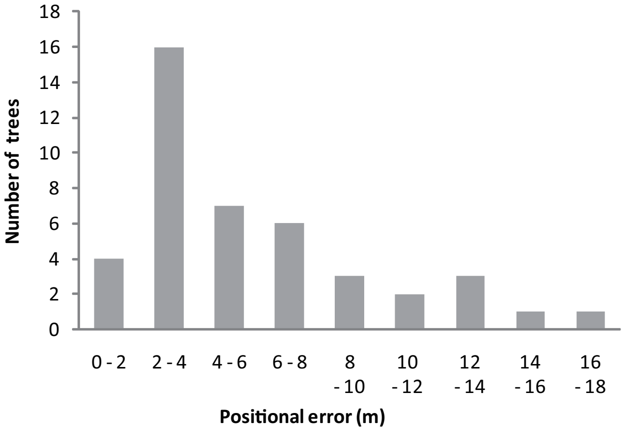


Figure 1. Frequency distribution of GPS positional error for all 43 measurements.

Figure 2 shows the magnitude and direction of GPS positional error at individual trees. In the upper unit, tree positions measured by GPS tended to be biased toward the southeast, while locations were relatively accurate in the lower unit. The tendency of positional error seems to be similar at adjacent trees, although it is not so distinct.

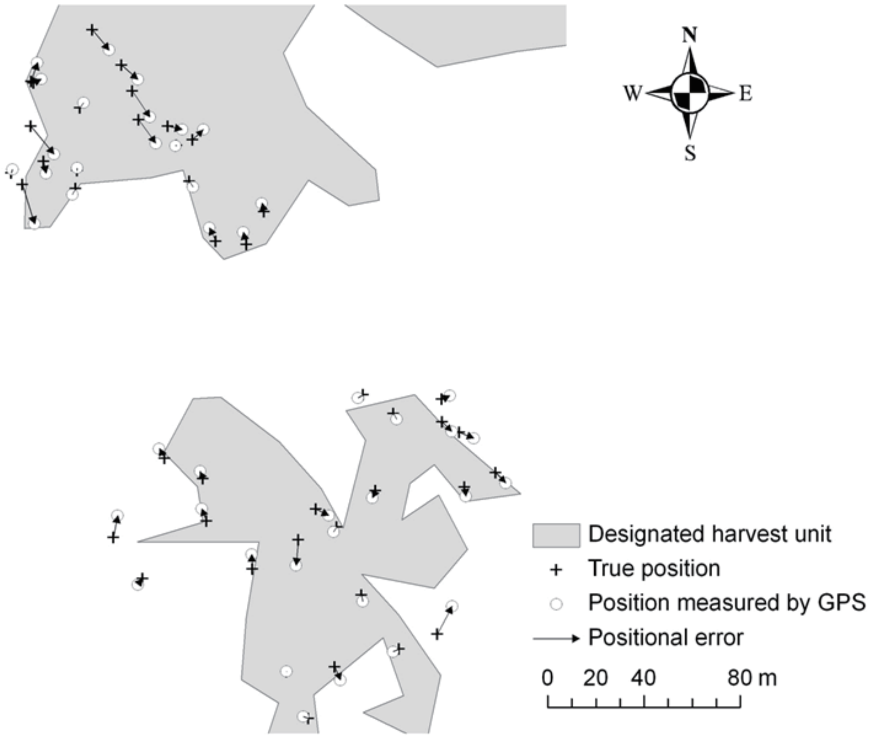


Figure 2. GPS positional error for individual trees (n = 43).

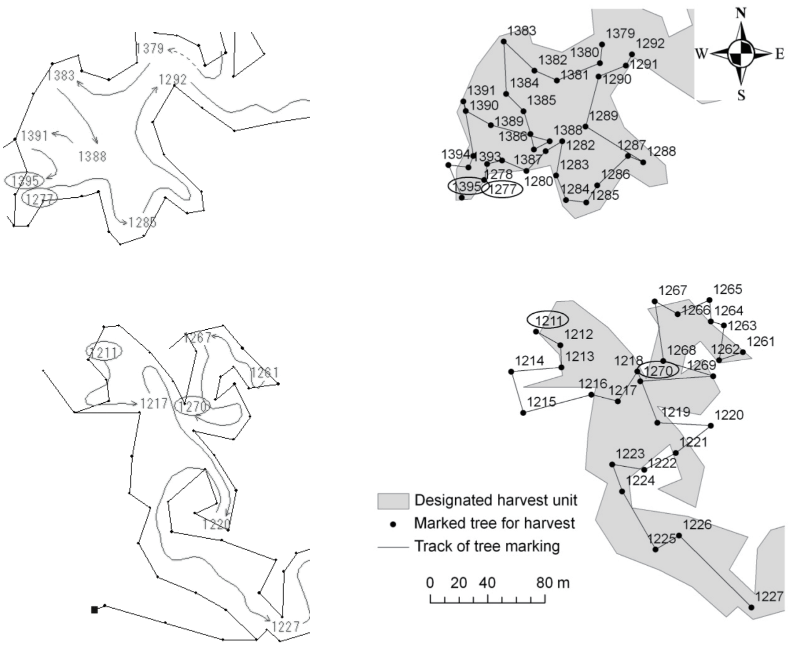
The length and direction of arrows represents the magnitude and direction of positional errors.

3.2 Mapping of Marked Trees

The GPS receiver successfully measured the positions of all marked trees (n = 1,565). Figure 3 shows the full results of tree marking for the study site. Tree locations were individually identified throughout the designated harvest units.

Figure 3. GPS mapping of marked trees (n = 1,565).

Figure 4 shows an enlarged map of the lower unit to contrast conventional and GPS-based mapping. On the conventional map, only the tree marker's tracks with the number of some trees were drawn. Because the map was drawn by hand, tree locations were rather rough and often unidentified. The GPS-generated map clearly provides positional information for individual trees; tree location can be identified even if it was selected outside the designated harvest unit.


(a) Conventional map

(b) GPS-based map

Figure 4. Conventional (a) and GPS-based (b) map of marked trees.

3.3 Spatial Analyses of Tree Marking

Figure 5 shows all marked trees, noting those that were within and those that were outside of the designated harvest units. Out of 1,565 trees, 1,155 (74%) were located within the designated units and 410 (26%) were outside, most of which were aligned along the harvest boundaries.

Figure 6 shows the spatial distribution of harvest intensity through-

Figure 5. Marked trees—inside (•) and outside (+) of the designated harvest units.

out the study site. The point density of marked trees was unevenly distributed. Figure 7 shows the aggregated area of stands selected for harvest (ha) according to the point density of marked trees (ha^{-1}). We observed a mono-modal distribution, with a mean point density of 35.3

trees ha^{-1}. Low harvest intensity (< 10 trees ha^{-1}) was observed on 2.51 ha (9%) of the study site, while trees were intensively marked for harvest (≥ 50 trees ha^{-1}) on 5.38 ha (18%).

Figure 6. Spatial distribution of harvest intensity.

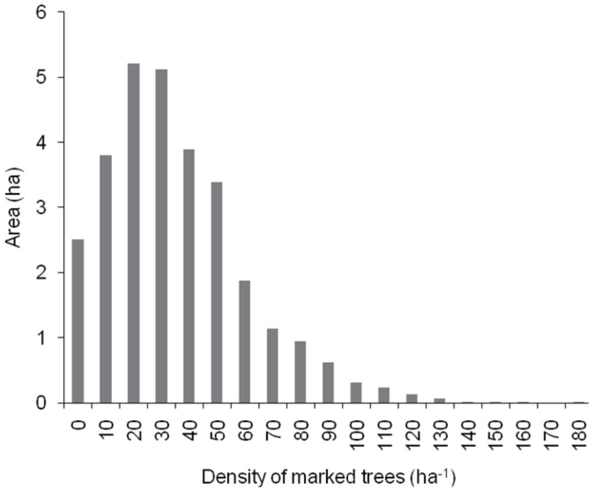


Figure 7. Aggregated area of stands selected for harvest (ha) according to the point density of marked trees (ha^{-1}).

4. Discussion

Owari *et al.* (2009) tested the positional accuracy of the same GPS receiver within the UT Hokkaido Forest during a defoliated season, and the mean positional error was 3.6 m. The locations of marked trees obtained through this study were relatively inaccurate compared to the previous examination. Owari *et al.* (2009) logged positions at an interval of one second, the duration of observation was 30 seconds, and each point location was averaged over time. In this study, however, instantaneous positions were logged by the GPS receiver. Because thousands of trees must be marked in a managed forest, it is unfeasible for a marker to remain at an individual tree for 30 or more seconds. Some positional accuracy must be sacrificed to pursue the practical use of GPS in a real-world context.

Although the GPS measurements obtained in this study were less accurate, they may be satisfactory for the purpose of mapping marked trees. When compared to the conventional map, the GPS-based map clearly provides more detailed and precise information about the locations of marked trees. Loggers and inspectors can also use positional information to quickly and efficiently locate trees. According to Takuma *et al.* (2009), the walking distance required to locate trees was reduced by 7-22% —as compared to conventional location techniques— when GPS navigation was used. Even though it has the potential to increase the efficiency of searching for harvest trees, loggers and inspectors should be cautious when using the positional data. Results indicated that tree locations obtained by GPS could be inaccurate (>10 m) in some cases.

This study also revealed details about the quality of conventional tree marking techniques; a considerable number of marked trees were located outside of the designated harvest area. Because most of these trees were located along harvest area boundaries, the positional inaccuracy of GPS measurements may have affected our results. Though some of this error may be due to mistakes made by the marker, marking decisions may also be conducted in an adaptive manner. In general, structural differences in growing stock, tree density, species composition, and size distribution are not so distinct on either side of the stand boundary. The tree marker may make a decision based on his observations of actual stand conditions.

We observed a variety of harvest intensities over the study site. Harvest intensity may be adjusted based on the single-tree selection policy—trees may be removed more intensively from a dense stand with high dominance and less intensively in a sparse stand with low dominance (Owari *et al.*, 2010b). Indeed, tree marking practices under a single-selection system are considered an adaptive form of forest management.

5. Conclusions

Results suggest GPS is a useful tool for managers and loggers to easily record the locations of marked trees for harvest. GPS-based mapping provides more precise information about the location of marked trees. The use of GPS helps maintain past harvest records and improve the quality of tree marking practices. Positional information obtained by GPS can enhance our understanding of how tree marking operations are implemented under the single-tree selection system.

Future research should address the following questions: 1) How can we improve the positional accuracy of GPS? 2) How can we reduce the cost and effort associated with using GPS in tree marking? and 3) How can we evaluate harvest impact on stand dynamics using the positional information obtained by GPS? By actively using innovative technologies like GPS, we can achieve more precise management of natural forests using the single-tree selection system.

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天然林択伐施業の選木における全地球測位システム (GPS) の利用

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要約: 北海道では単木択伐による天然林施業が広く行われてきた。選木は森林経営の目的に従って収穫木を慎重に選ぶもので、択伐施業において重要な作業である。実際にどの木を収穫するかは、施業担当者が訓練や経験を通じて身につけた技能に基づき決めている。収穫木の正確な位置情報を記録することは従来難しかったが、最近の全地球測位システム (GPS) 技術の向上によって位置をピンポイントで特定できるようになった。そこで本研究では、単木択伐施業の選木における GPS 技術の実用性について試験を行った。東京大学北海道演習林内の択伐対象林分 29.23ha において計 1,565 本が収穫木として選ばれた。携帯式 GPS 受信機を用いて収穫木全ての座標を記録した。43 本の収穫木についてレーザー距離計と電子コンパスモジュールを用いた閉合トラバース測量により正確な座標を取得し、測位精度を調べた。その結果、GPS 受信機の平均測位誤差は 5.7m であった。収穫木の GPS 測位データから林分内における伐採強度の空間的な分布を明らかにできた。調査結果から、GPS 技術は単木択伐施業のもとで森林をより精密に管理経営するために有用なツールであると考えられた。

キーワード: GPS, 天然林施業, 単木択伐, 選木