Developing a repeatable workflow for monitoring sub-meter landscape change in Muir Woods National Monument: New strategies for Ecosystem Management Using Terrestrial Laser Scanning

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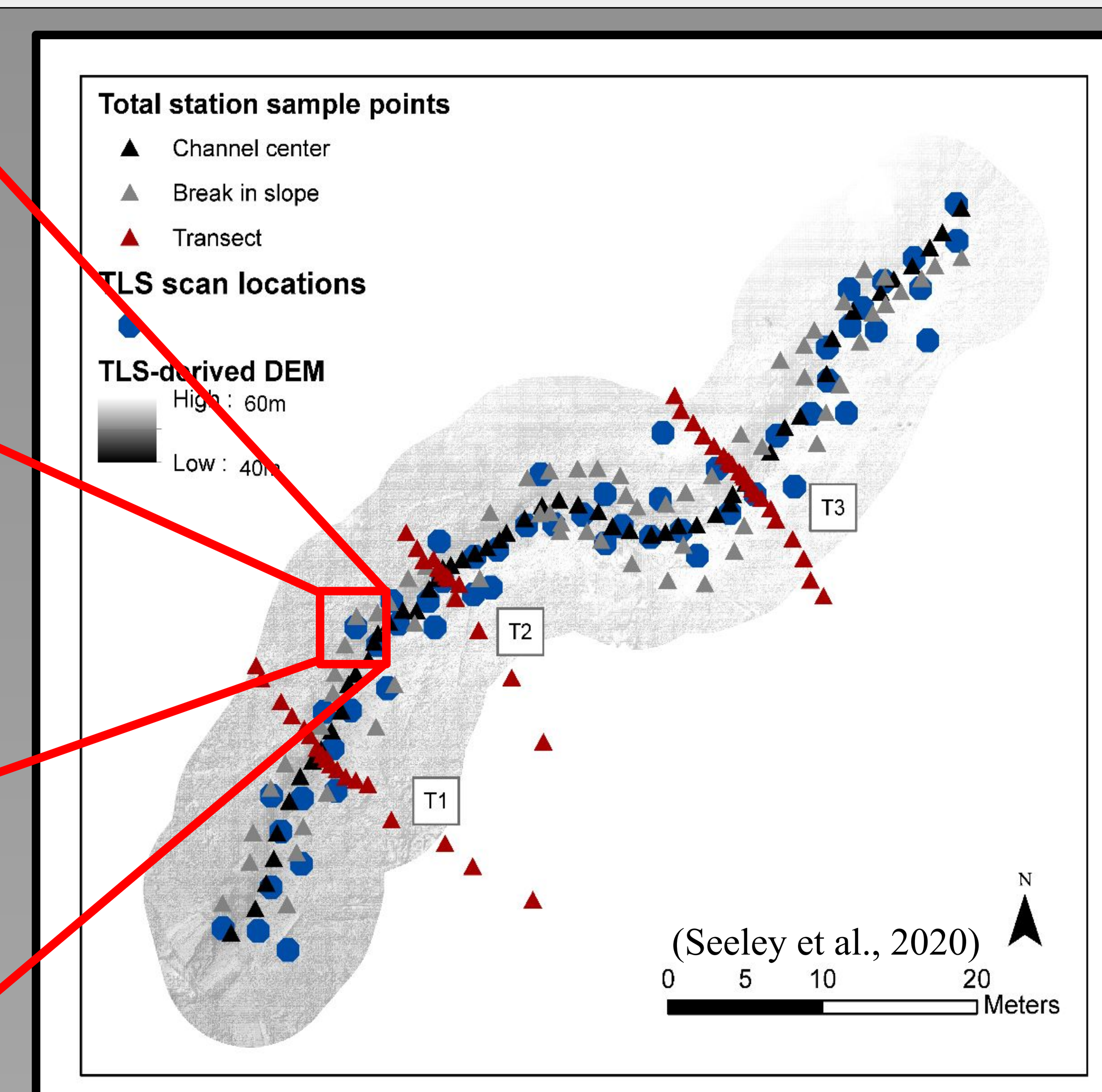
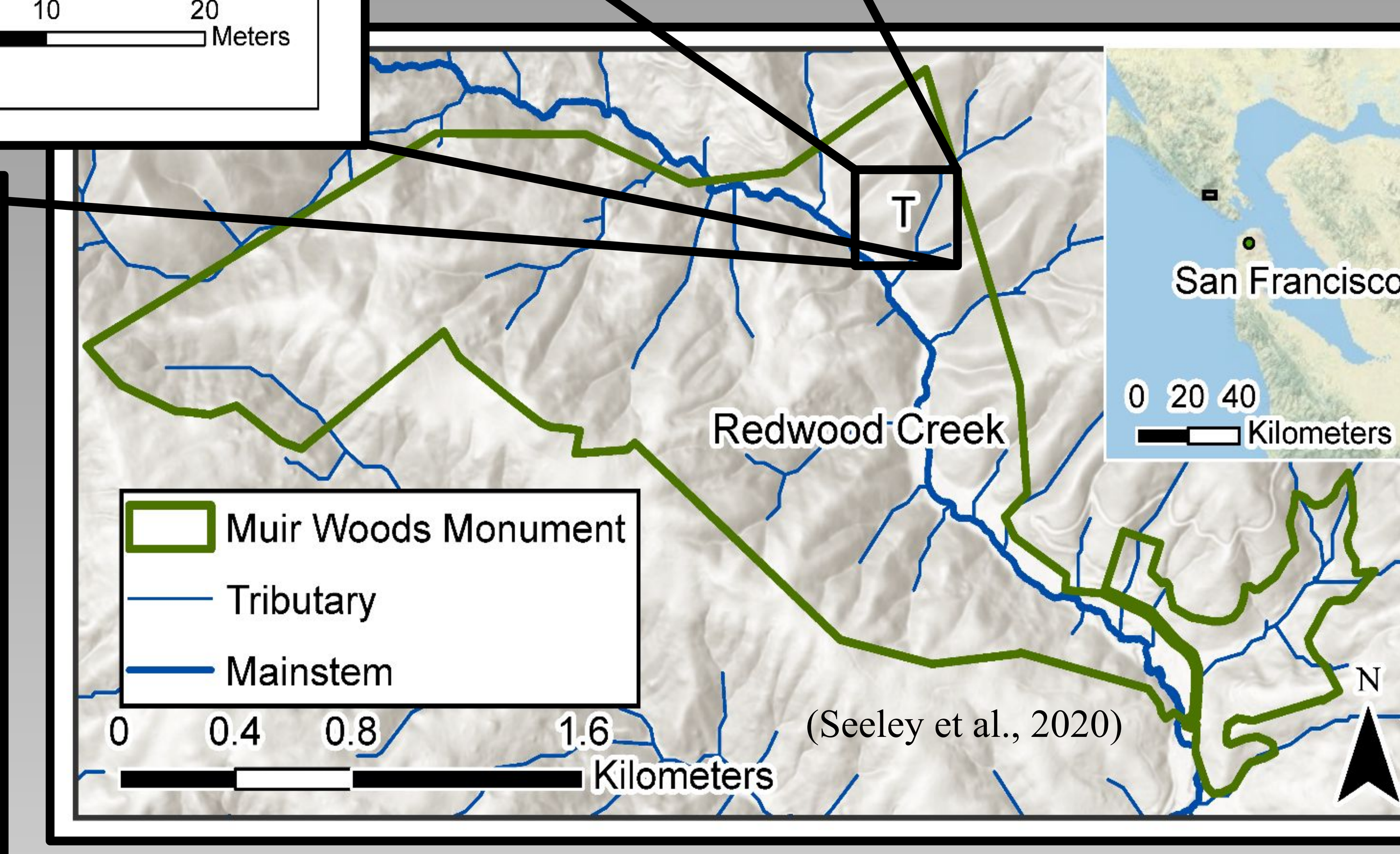
Abstract

Assessing changes in environmental structure over time is crucial for preserving, rehabilitating, and restoring ecosystems that have been impacted by human activity. Terrestrial Laser Scanning systems (TLS) are uniquely positioned to tackle this challenge due to their ease of use, high data output, and precise measurements. However, the widespread adoption of TLS systems is currently limited by the lack of a documented workflow specifically for ecosystem management applications. To address this need, we have developed a repeatable TLS workflow for monitoring sub-meter geomorphic changes in small, complex, streambeds in Muir Woods National Monument throughout multi-year surveys. Our initial findings are promising and reveal that TLS can detect environmental changes of ±0.08 m over annual timescales. However, aligning 3D data from TLS with survey points taken in the field, a critical step, remains a significant challenge that requires further attention. Our findings contribute to the exciting potential of TLS systems to be used by land managers to monitor detailed environmental changes accurately. Furthermore, the workflow allows for monitoring strategies and a scale and accuracy that is nearly impossible with currently existing methods.

1 Data Collection Overview

The study focused on two tributaries within the research area, designated as ID 1660 and ID 1450. We conducted detailed 3D geomorphological scans from July to September over the course of 3 years. A **Leica BLK 360 Terrestrial Laser Scanner (TLS)** was employed, set to medium resolution for comprehensive coverage. Each tributary was scanned in multiple locations, with **each scanning session comprising potentially 50 individual scans** to capture extensive RGB and HDR imaging data.





2 Georeferencing and Point Cloud Processing

Georeferencing was performed using a Leica C10 total station, which tagged monuments visible within the scans. Through visual identification of targets within each scan, we assigned corresponding geolocations as determined by the total station. **Following alignment, the point clouds were rasterized to generate a Digital Terrain Model (DTM)** of each streambed. This rasterization process was critical for visualizing the geomorphic characteristics of the streams in a two-dimensional format.

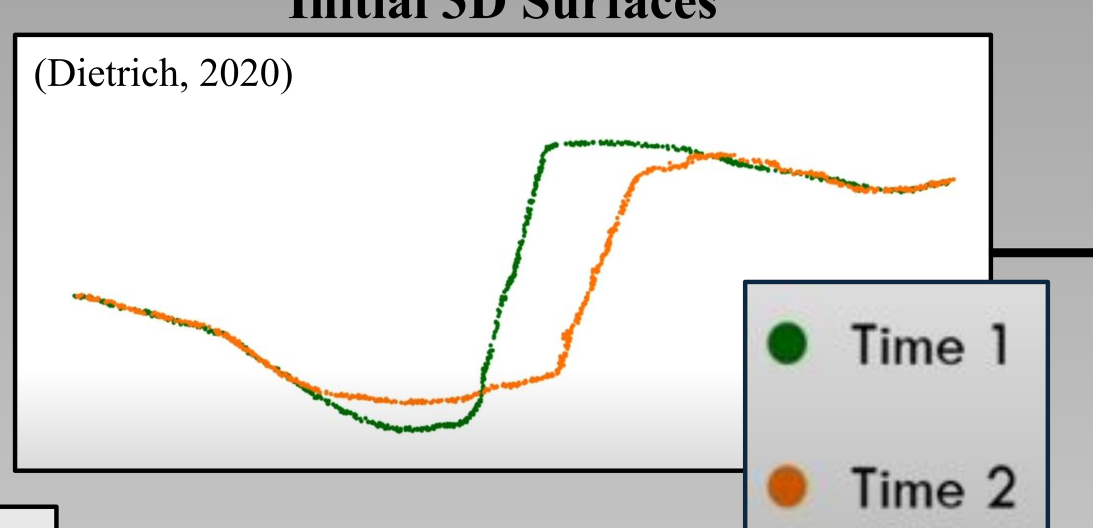
3 Challenges in Data Alignment

Despite human operators having awareness of spatial positioning, **the computer needs a framework of explicit coordinates to place the 3D data within a global context**. This was achieved by employing a total station, which provided precise locational data, essential for aligning the TLS data spatially. However, the **integration of data** from the total station and the **TLS presented substantial challenges** due to their inherent operational differences, necessitating alignment procedures to minimize errors and ensure that observed changes were attributable to actual geomorphic variations rather than positional inaccuracies.

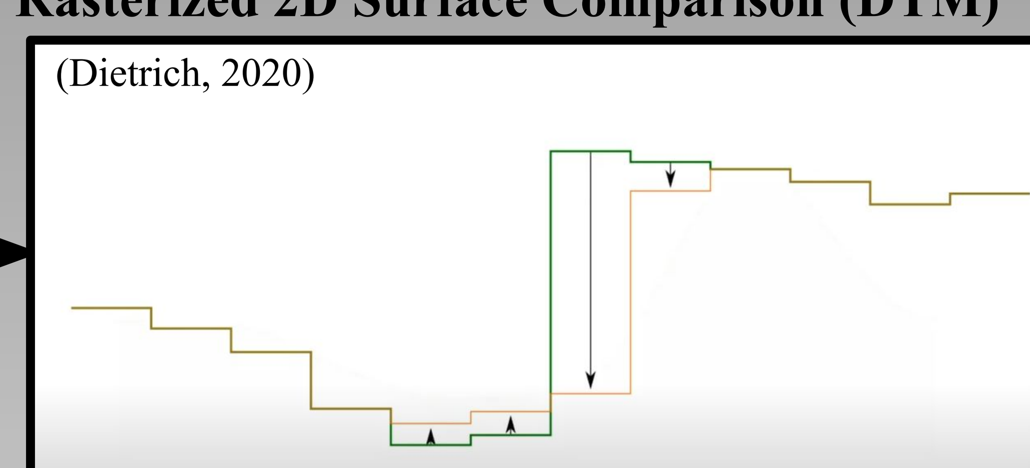
4 Advancements in Change Detection

The final stage involved **comparing DTMs** from different time points **to quantify geomorphic changes over time**. Traditionally, such analysis might overlook data gaps caused by the physical geometry of incised tributaries. However, **advancements in software now allow for direct comparison of 3D surface representation.** This approach not only accommodates the inherent georeferencing errors but also reduces the need for perfect scan alignment, thus enhancing the reliability of our temporal change analysis.

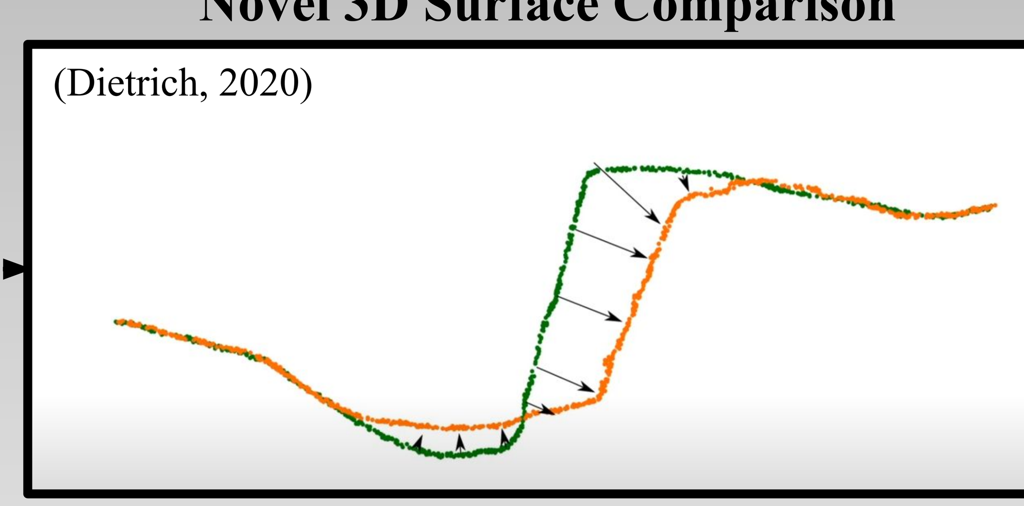
Initial 3D Surfaces



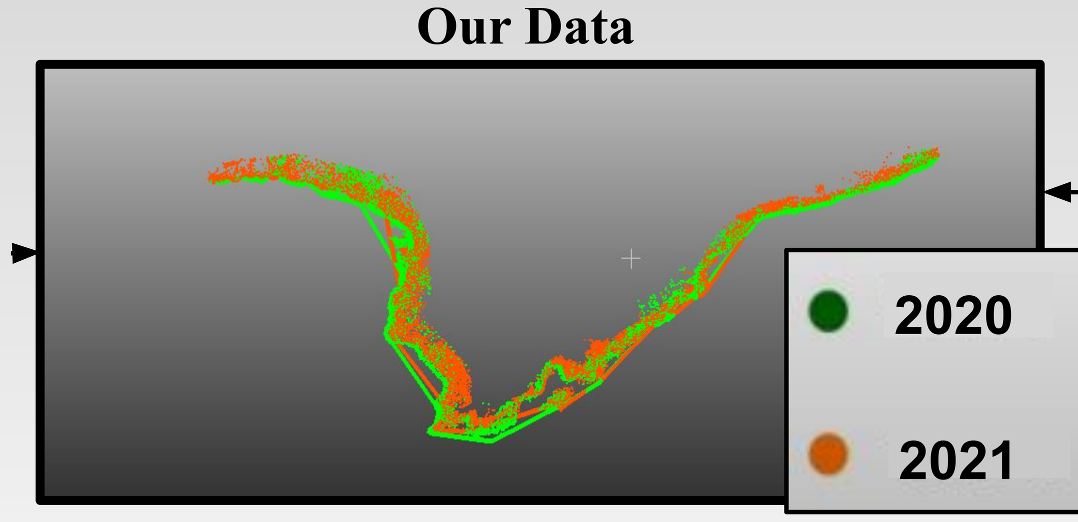
Rasterized 2D Surface Comparison (DTM)

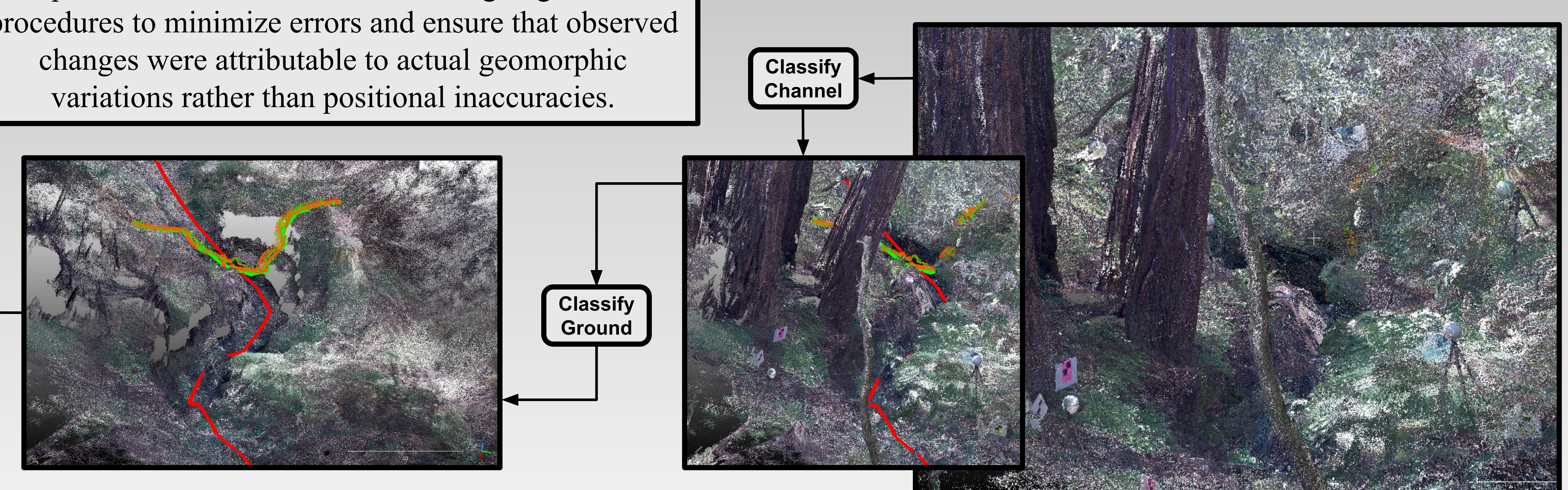


Novel 3D Surface Comparison



Our Data





Leveraging Terrestrial Laser Scanning Systems for Hemispherical Photography in Forest Canopy Analysis: Application of Airborne Derived Synthetic Hemispherical Photography Workflows to Terrestrial Conditions.

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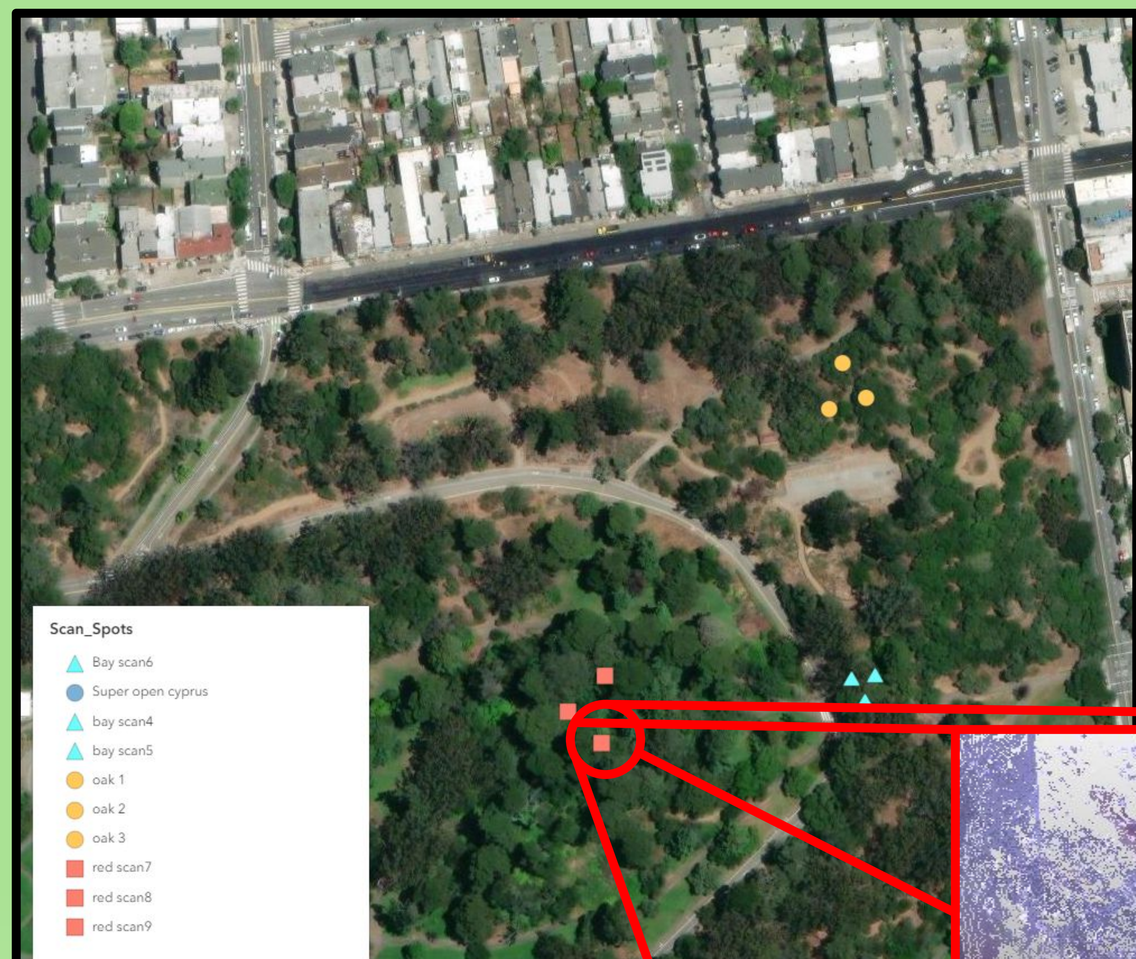
Abstract

Hemispherical photography is a well-established and widely used technique in ecological research to derive many characteristics of forest canopy structure. However, the process is resource-intensive, requiring significant labor and time investment, thus limiting its potential application in forest resource management. The accuracy of the results also depends on weather conditions at certain times of day, further limiting use in specific ecosystems. Our study aims to develop a straightforward methodology using open-source software to derive synthetic hemispherical photos using a Terrestrial Laser Scanning system (TLS). TLS systems are already in use for forest management projects worldwide and could be leveraged for additional applications in the field. Our study investigates whether TLS products are consistent with traditional hemispherical photography. Additionally, we would like to know whether synthetic photos are comparable to those obtained from conventional hemispherical photography methods. Initial results indicate that TLS systems can be used as a reliable alternative to traditional methods for hemispherical photography, providing a cost-effective alternative for obtaining critical forest canopy measurements.

1 Traditional Methods for Canopy GF

Traditional ways of estimating canopy gap fraction **use a camera** attached to a gimbal **with a specific fisheye lens**. In this case, the lens was an equal area projection meant to preserve area throughout the image taken. The process is the preferred method and gold standard to measure GF (Gap Fraction). However, **this method can only be used at certain times of the day due to over saturation by light. The processing of this data is also subjective and lab technicians need to have numerous hours of training to effectively differentiate canopy from sky.**

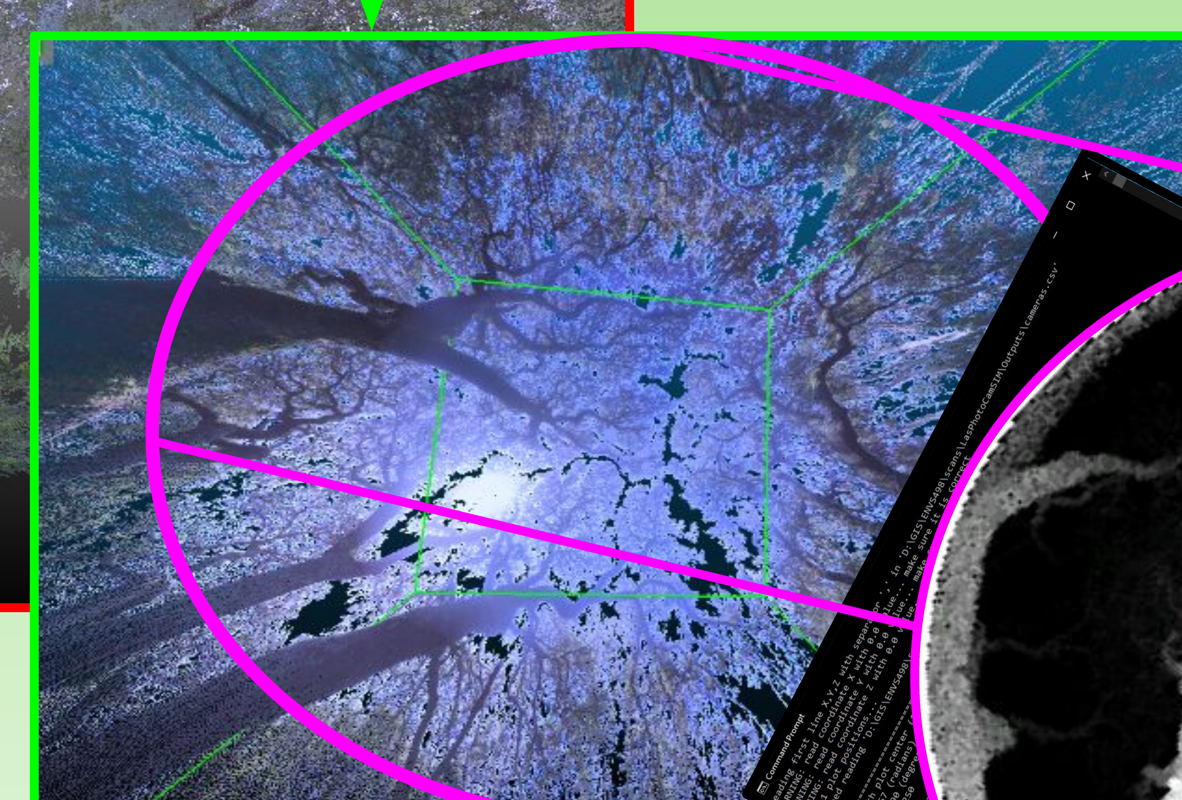


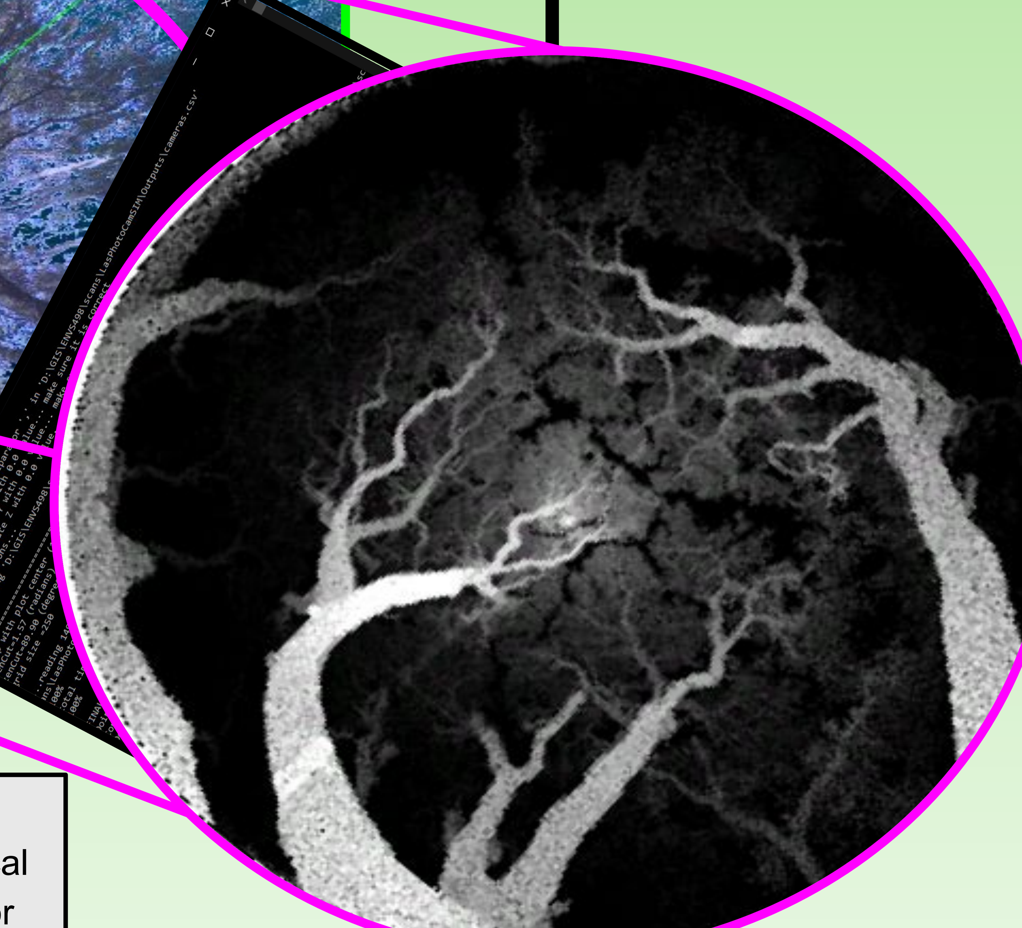
2 Plot Parameters and Characteristics

Plots in Golden Gate Park were chosen for higher canopy cover and homogenous species types. After determining three plots, each plot had three sites for scanning and hemispherical photography. All three scans were taken at each plot, all individual of each other. The first plot considered high coverage coast live oaks with a low canopy height. The second plot had a dense coverage of California Bay laurels and other surface herbaceous cover, with a higher canopy coverage nearing 40ft. The third and final plot was under coastal redwoods with canopies surpassing 60 ft. Little to no vegetation was present on the first two redwood sites, with the last having the surface entirely covered in ivy.

3 Data Preparation and Processing

Each **resulting scan** was between **300 and 400 MB** of data and consisted of just under **15 million points**. Using a random point deletion method, point **clouds were reduced by 60%** of their initial number before noticeable effects on GF are detected. Because hemispherical photos are oriented north, all site locations had north marked by a fluorescent flag. In Cloud Compare, we **oriented the point clouds to line up the scanned flag with the direction of the positive Y axis** to replicate the best hemispherical photography. Previous studies have normalized their scans; however, we have not found any reason to normalize our scans, as normalizing scans tended to shift the point.





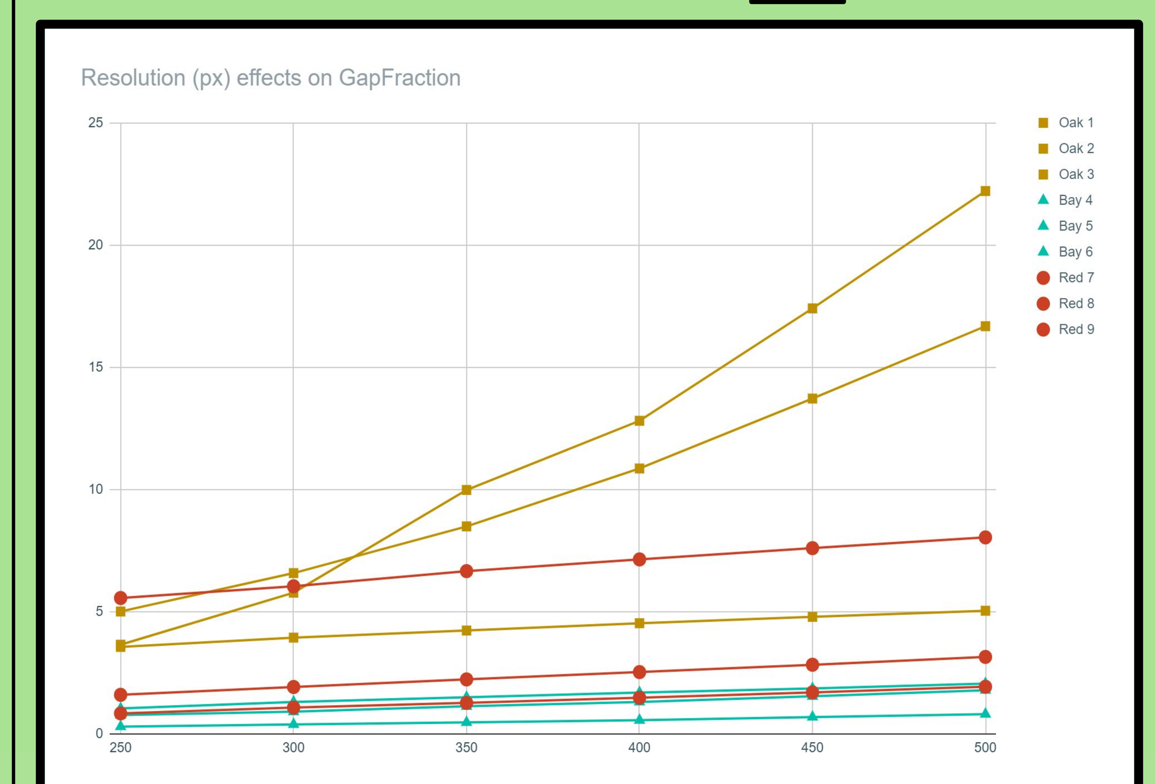
4 TLS Processing Methodology

Pirotti (2022) developed the program used to derive synthetic hemispherical photographs. The software was designed for sUAS applications to find GF for photogrammetrically derived point clouds. **It uses a point-based approach to estimate closure by projecting a user-defined grid in a user-defined orientation and then traces all points to the camera source.** If a point intersects a projected pixel, it is added to the pixel value. Resulting grids are projected in an ESRI ASCII format, with each pixel value corresponding to the number of points intersecting it. **The user can set parameters to manipulate variables** that affect **point tracking, pixel size, projection type, etc.**

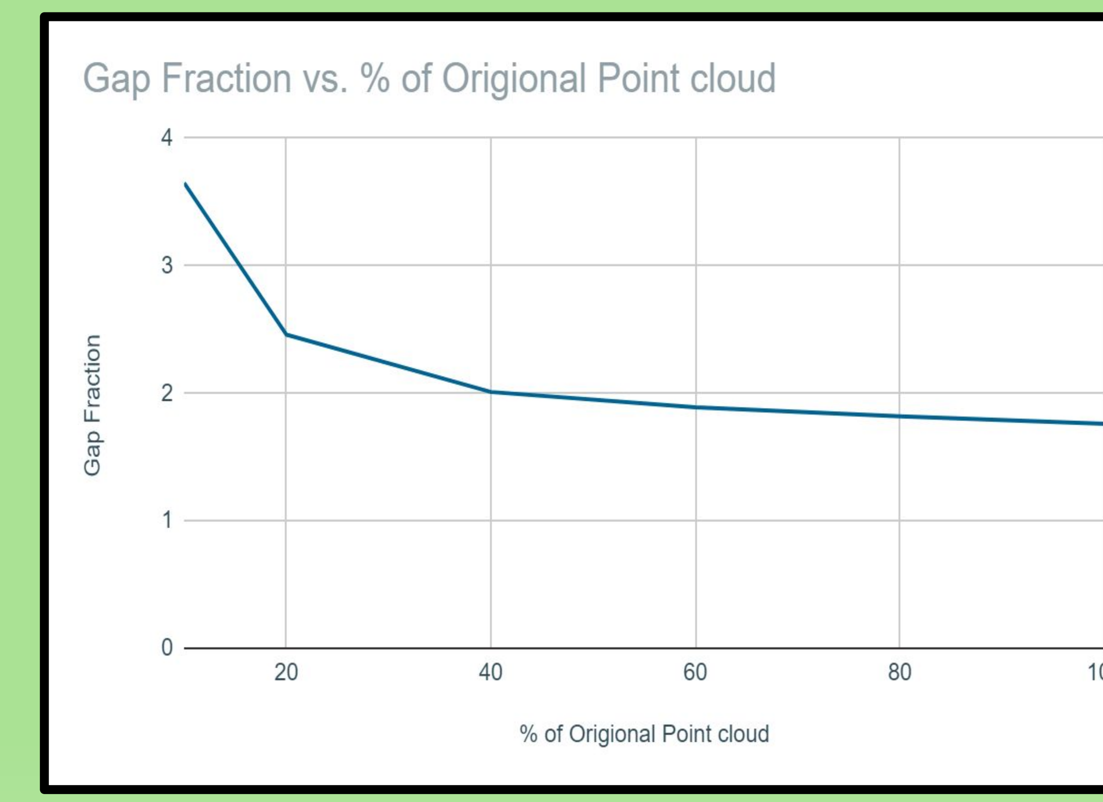
5 Resulting Findings

This resulting ESRI ACSII raster shows where in the forest canopy we have **gaps (white)** and where we have t**ree coverage (black)**. This data can be used for a plethora of applications, however we are most **interested in** the amount of **solar radiation that reaches** our scanner an application that can be used for both environmental forest management and ecological reasons.

6 Discoveries



Strong positive correlations between pixel count and percent Gap Fraction was observed in all scans. This is due to the software's methodology, which "counts" the points that intersect a projected pixel. Since the resolution of the hemispherical photograph was 250 pixels in diameter, we used that as our initial base value.



Initial data processing showed how the **decimation of point clouds had little impact on the percent Canopy Gap Fraction.** Because of this, all point clouds were reduced to 60 percent of their initial return numbers for faster data processing purposes.