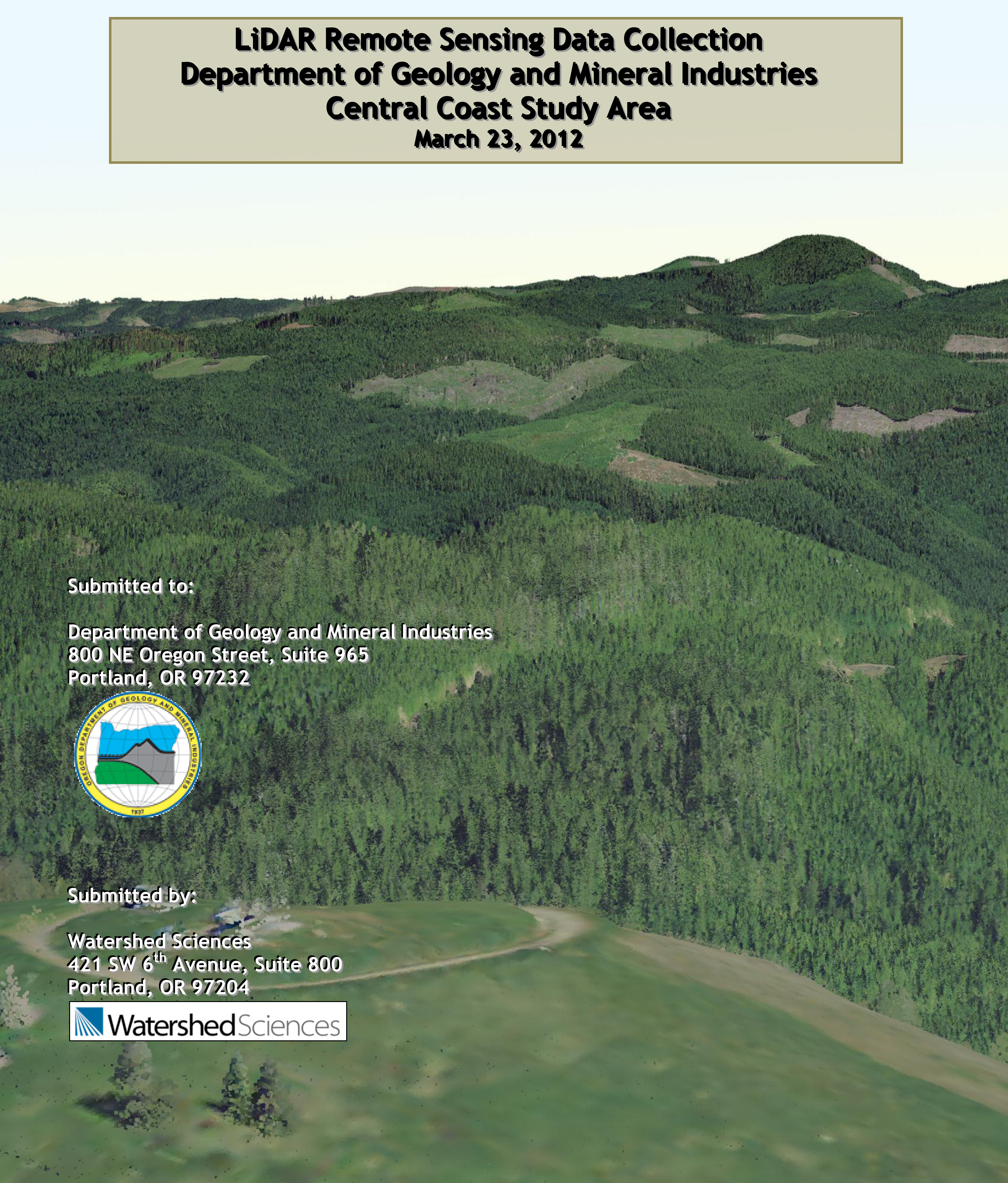
LiDAR Remote Sensing Data Collection
Department of Geology and Mineral Industries
Central Coast Study Area
March 23, 2012



Submitted to:

Department of Geology and Mineral Industries
800 NE Oregon Street, Suite 965
Portland, OR 97232

Submitted by:

Watershed Sciences
421 SW 6th Avenue, Suite 800
Portland, OR 97204

LiDAR Remote Sensing Data Collection:
DOGAMI, Central Coast Study Area

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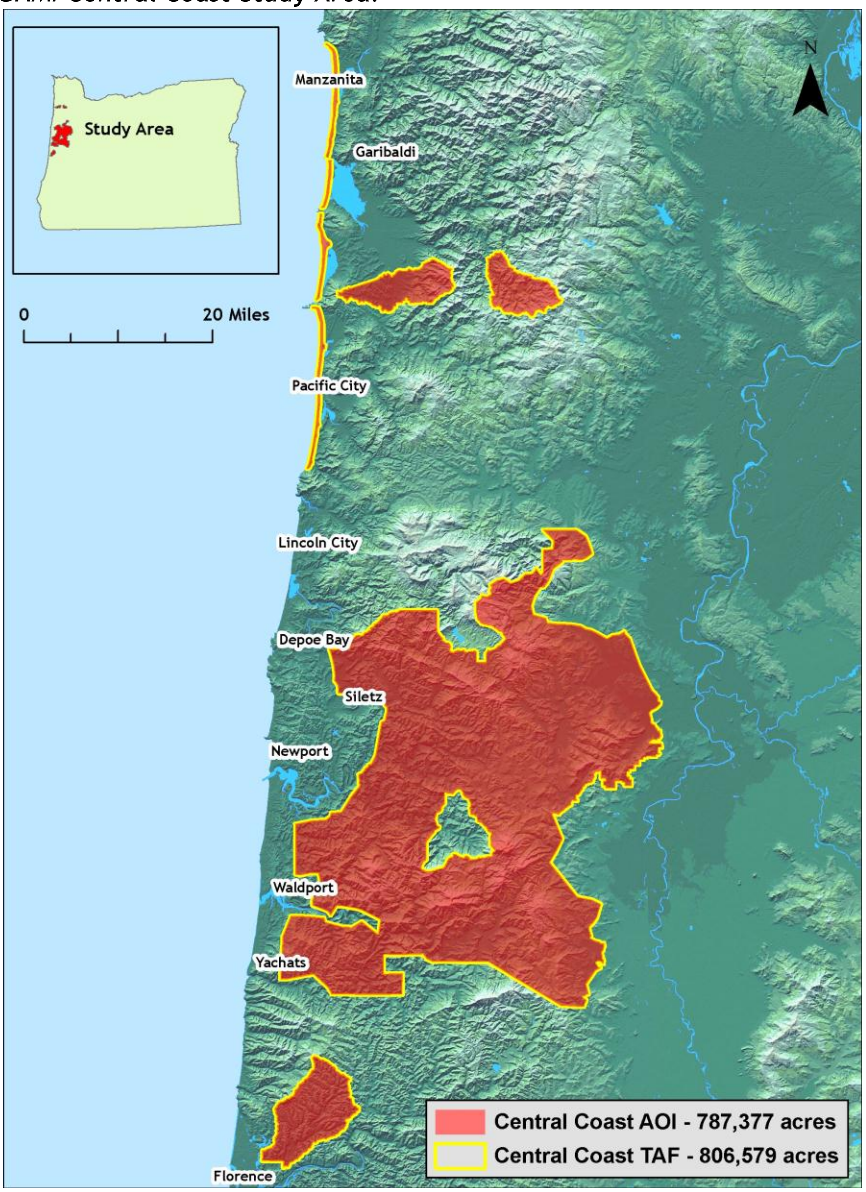
1. Overview

1.1 Study Area

Watershed Sciences, Inc. has collected Light Detection and Ranging (LiDAR) data of the Oregon Central Coast Study Area for the Oregon Department of Geology and Mineral Industries (DOGAMI). The Central Coast area of interest (AOI) totals 1,230 square miles (787,377 acres) and the total area flown (TAF) covers 1,260 square miles (806,579 acres). The TAF acreage is greater than the original AOI acreage due to buffering and flight planning optimization (**Figure 1.1** below). Central Coast data are delivered in: OGIC (HARN): Projection: Oregon Statewide Lambert Conformal Conic; horizontal and vertical datum: NAD83 (HARN)/NAVD88 (Geoid03); units: International Feet.

Figure 1.1. *DOGAMI Central Coast Study Area.*



1.2 Area Delivered to Date

Table 1.1. Total delivered acreage to date is detailed below.

DOGAMI Central Coast Study Area				
	Delivery Date	**Acquisition Dates**	**AOI Acres**	**TAF Acres**
Delivery Area 1	January 31, 2012	September 2, 2011– November 22, 2011	**276,786**	**286,394**
Delivery Area 2	March 23, 2012	September 4, 2011 – February 3, 2012	**230,040**	**234,923**

Figure 1.2. *Central Coast Delivery area 2.*

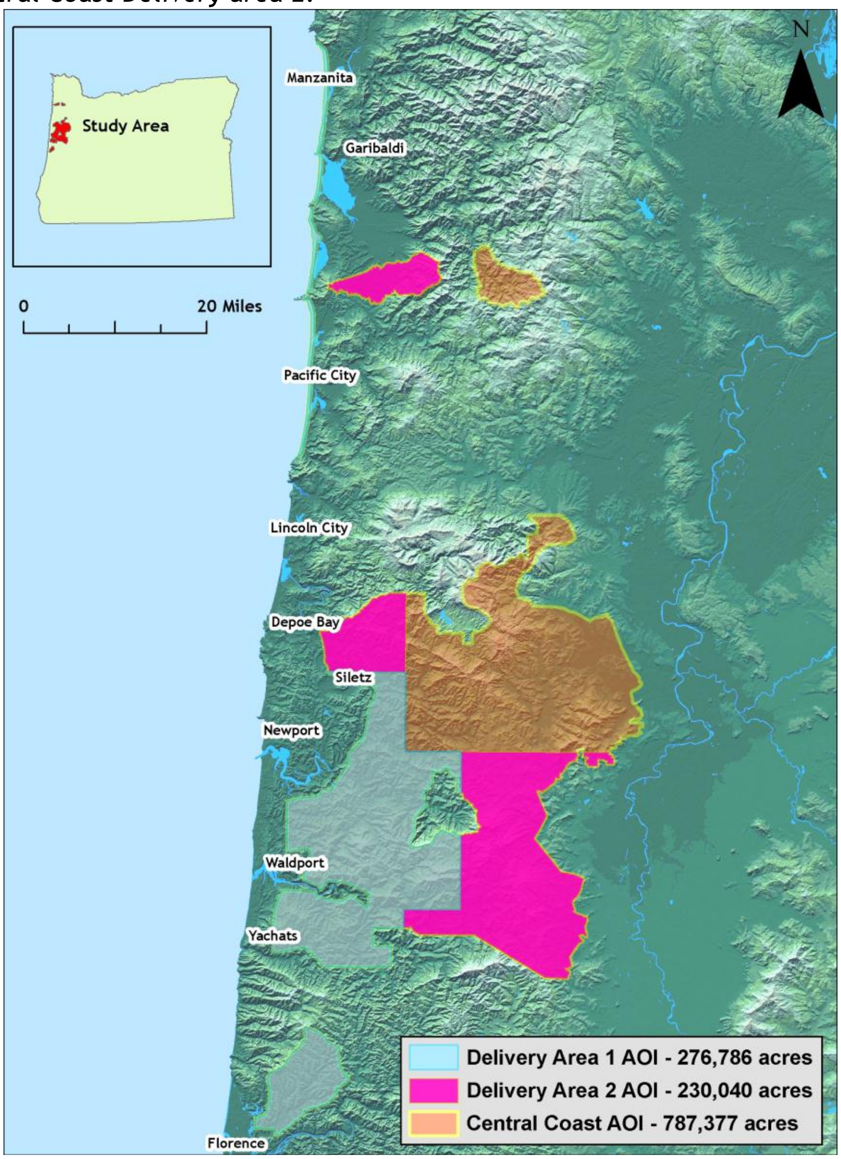
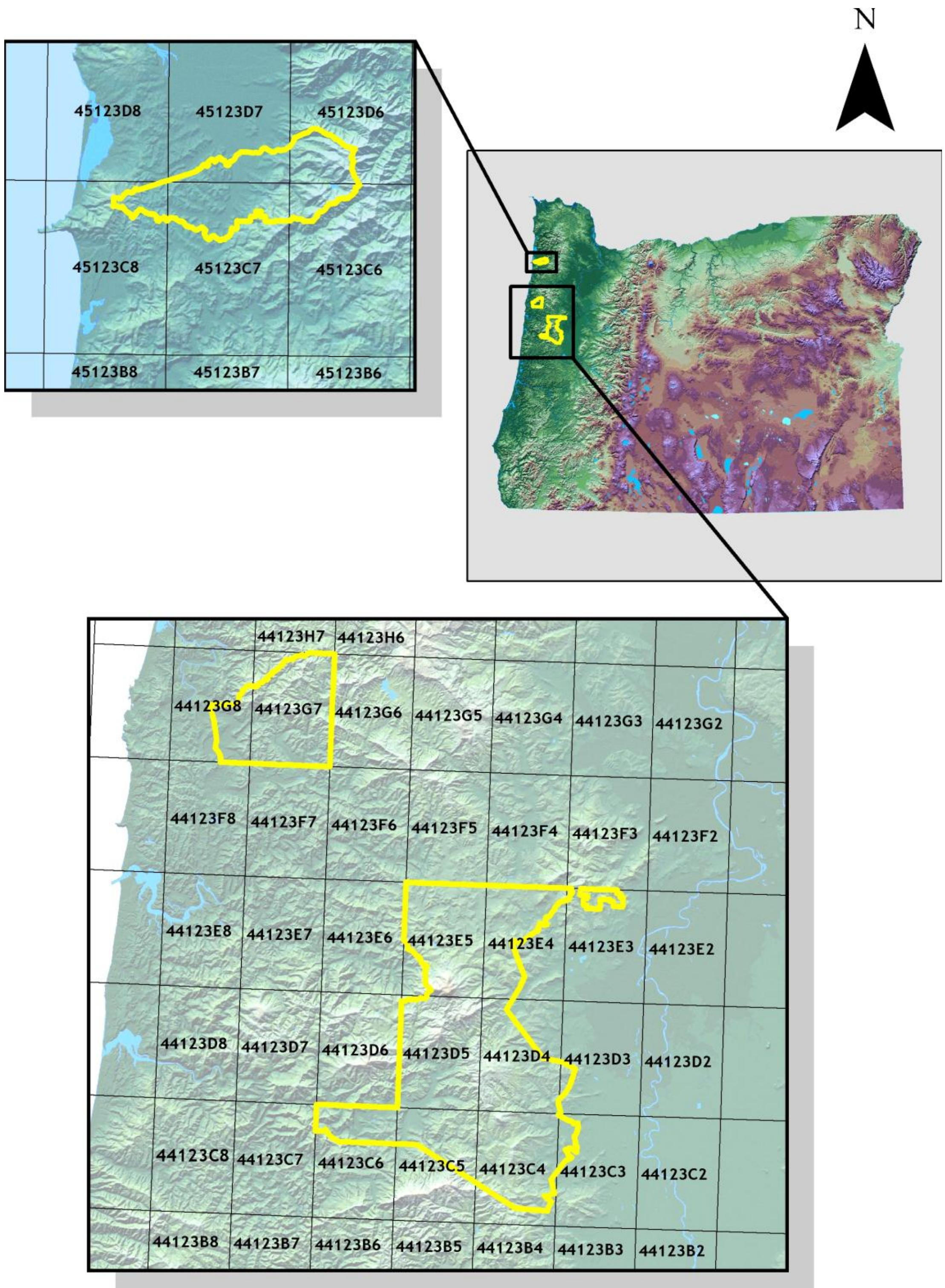


Figure 1.3. *Central Coast Delivery area 2, illustrating the delivered 7.5 minute USGS quads.*



2. Acquisition

2.1 Airborne Survey Overview – Instrumentation and Methods

The LiDAR survey utilized Leica ALS50, ALS60 and ALS70 sensors mounted in Cessna Caravan 208B and Partenavia P.38 aircrafts. The systems were set to acquire ≥105,000 laser pulses per second (i.e. 105 kHz pulse rate) and flown at 900 and 1400 meters above ground level (AGL), capturing a scan angle of $\pm 14^{\circ}$ from nadir[1]. These settings are developed to yield points with an average native density of ≥8 points per square meter over terrestrial surfaces. The native pulse density is the number of pulses emitted by the LiDAR system. Some types of surfaces (i.e. dense vegetation or water) may return fewer pulses than the laser originally emitted. Therefore, the delivered density can be less than the native density and lightly variable according to distributions of terrain, land cover and water bodies.

The Cessna Caravan is a powerful, stable platform, which is ideal for the often remote and mountainous terrain found in the Pacific Northwest. The Leica ALS60 sensor head installed in the Caravan is shown on the right.

Table 2.1 *LiDAR Survey Specifications*

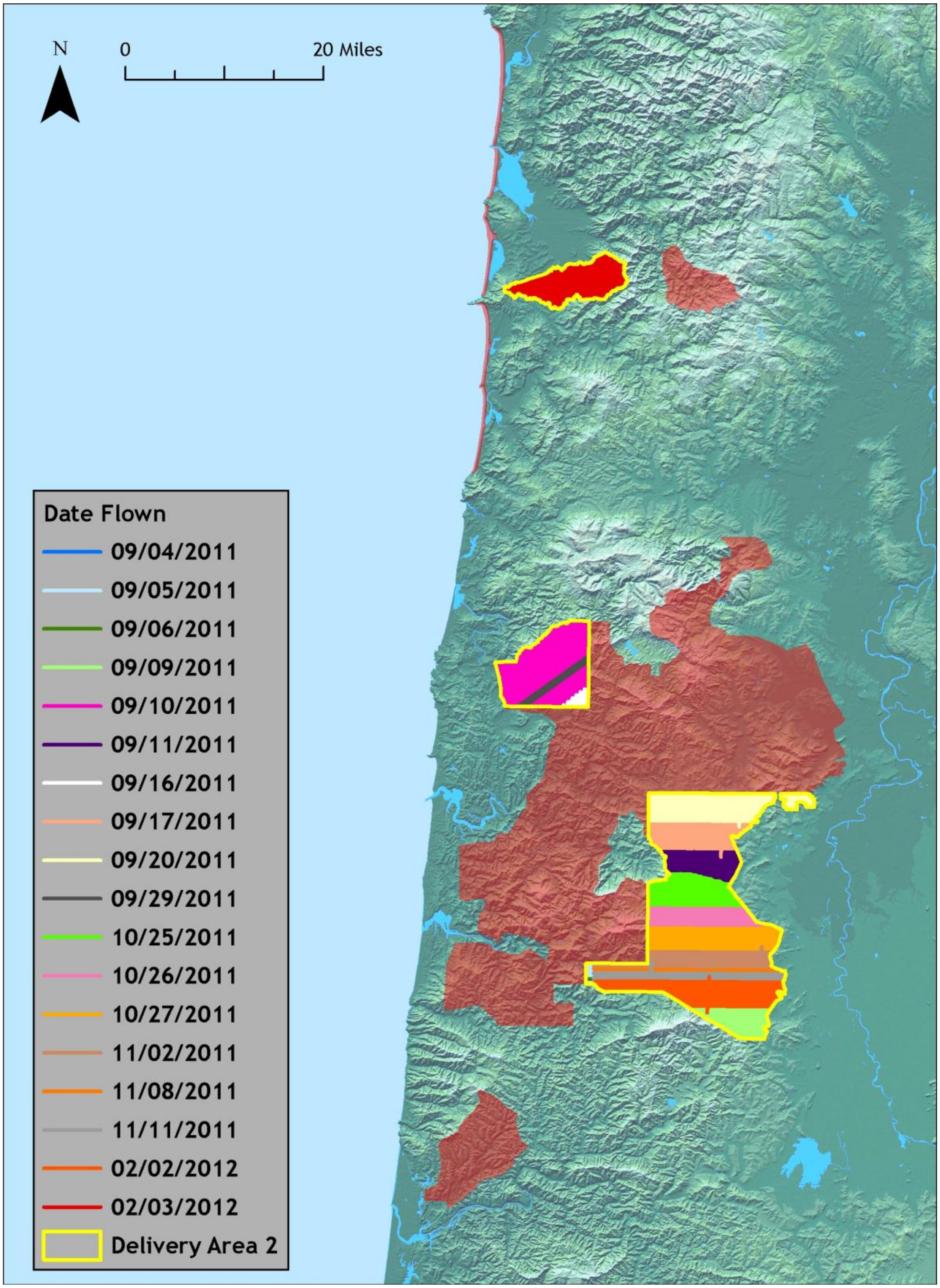
Sensors	Leica ALS50, ALS60, ALS70
Survey Altitude (AGL)	900 m and 1400 m
Pulse Rate	>105 kHz
Pulse Mode	Single
Mirror Scan Rate	52 Hz
Field of View	30° ($\pm 15^{\circ}$ from nadir)
Roll Compensated	Up to 15°
Overlap	100% (60% Side-lap)

The study area was surveyed with opposing flight line side-lap of ≥60% (≥100% overlap) to reduce laser shadowing and increase surface laser painting. The system allows up to four range measurements per pulse, and all discernable laser returns were processed for the output dataset.

To solve for laser point position, it is vital to have an accurate description of aircraft position and attitude. Aircraft position is described as x, y and z and measured twice per second (2 Hz) by an onboard differential GPS unit. Aircraft attitude is measured 200 times per second (200 Hz) as pitch, roll and yaw (heading) from an onboard inertial measurement unit (IMU). **Figure 2.1** shows the flight lines completed for current processing.

[1] Nadir refers to the perpendicular vector to the ground directly below the aircraft. Nadir is commonly used to measure the angle from the vector and is referred to a "degrees from nadir".

Figure 2.1. *Actual flightlines for the Central Coast Study Area illustrating the dates flown for processing.*



2.2 Ground Survey – Instrumentation and Methods

During the LiDAR survey, static (1 Hz recording frequency) ground surveys were conducted over monuments with known coordinates. Monument coordinates are provided in **Table 2.2** and shown in **Figure 2.2**. After the airborne survey, the static GPS data were processed using triangulation with CORS stations and checked against the Online Positioning User Service (OPUS[2]) to quantify daily variance. Multiple sessions were processed over the same monument to confirm antenna height measurements and reported position accuracy.

2.2.1 Instrumentation

For this study area all Global Navigation Satellite System (GNSS[3]) survey work utilizes a Trimble GPS receiver model R7 with a Zephyr Geodetic antenna with ground plane for static control points. The Trimble GPS R8 unit is used primarily for Real Time Kinematic (RTK) work but can also be used as a static receiver. For RTK data, the collector begins recording after remaining stationary for 5 seconds then calculating the pseudo range position from at least three epochs with the relative error under 1.5 cm horizontal and 2 cm vertical. All GPS measurements are made with dual frequency L1-L2 receivers with carrier-phase correction.

2.2.2 Monumentation

Whenever possible, existing and established survey benchmarks shall serve as control points during LiDAR acquisition including those previously set by Watershed Sciences. In addition to NGS, the county surveyor's offices and the Oregon Department of Transportation (ODOT) often establish their own benchmarks. NGS benchmarks are preferred for control points. In the absence of NGS benchmarks, county surveys, or ODOT monumentation, Watershed Sciences produces our own monuments. These monuments are spaced at a minimum of one mile and every effort is made to keep these monuments within the public right of way or on public lands. If monuments are required on private property, consent from the owner is required. All monumentation is done with 5/8" x 30" rebar topped with a 2" diameter aluminum cap stamped "Watershed Sciences, Inc.".

[2] Online Positioning User Service (OPUS) is run by the National Geodetic Survey to process corrected monument positions.
[3] GNSS: Global Navigation Satellite System consisting of the U.S. GPS constellation and Soviet GLONASS constellation

2.2.3 Methodology

Each aircraft is assigned a ground crew member with two R7 receivers and an R8 receiver. The ground crew vehicles are equipped with standard field survey supplies and equipment including safety materials. All control points are observed for a minimum of two survey sessions lasting no fewer than 2 hours. At the beginning of every session the tripod and antenna are reset, resulting in two independent instrument heights and data files. Data are collected at a rate of 1Hz using a 10 degree mask on the antenna.

The ground crew uploads the GPS data to the Dropbox website on a daily basis to be returned to the office for Professional Land Surveyor (PLS) oversight, Quality Assurance/Quality Control (QA/QC) review and processing. OPUS processing triangulates the monument position using 3 CORS stations resulting in a fully adjusted position. CORPSCON[4] 6.0.1 software is used to convert the geodetic positions from the OPUS reports. After multiple days of data have been collected at each monument, accuracy and error ellipses are calculated. This information leads to a rating of the monument based on FGDC-STD-007.2-1998[5] Part 2 **(Table 2.2)** at the 95% confidence level.

All RTK measurements are made during periods with a Position Dilution of Precision (PDOP) of ≤ 3.0 and in view of at least six satellites by the stationary reference and roving receiver. RTK positions are collected on 20% of the flight lines and on bare earth locations such as paved, gravel or stable dirt roads, and other locations where the ground is clearly visible (and is likely to remain visible) from the sky during the data acquisition and RTK measurement period(s). In order to facilitate comparisons with LiDAR measurements, RTK measurements are not taken on highly reflective surfaces such as center line stripes or lane markings on roads. RTK points are taken no closer than one meter to any nearby terrain breaks such as road edges or drop offs. In addition, it is desirable to include locations that can be readily identified and occupied during subsequent field visits in support of other quality control procedures described later. Examples of identifiable locations would include manhole and other flat utility structures that have clearly indicated center points or other measurement locations. In the absence of utility structures, a PK nail can be driven into asphalt or concrete and marked with paint.

Multiple differential GPS units are used in the ground based real-time kinematic (RTK) portion of the survey. To collect accurate ground surveyed points, a GPS base unit is set up over monuments to broadcast a kinematic correction to a roving GPS unit. The ground crew uses a roving unit to receive radio-relayed kinematic corrected positions from the base unit. This RTK survey allows precise location measurement ($\sigma \leq 1.5$ cm). **Figure 2.3** shows subsets of these RTK locations.

[4] U.S. Army Corps of Engineers , Engineer Research and Development Center Topographic Engineering Center software

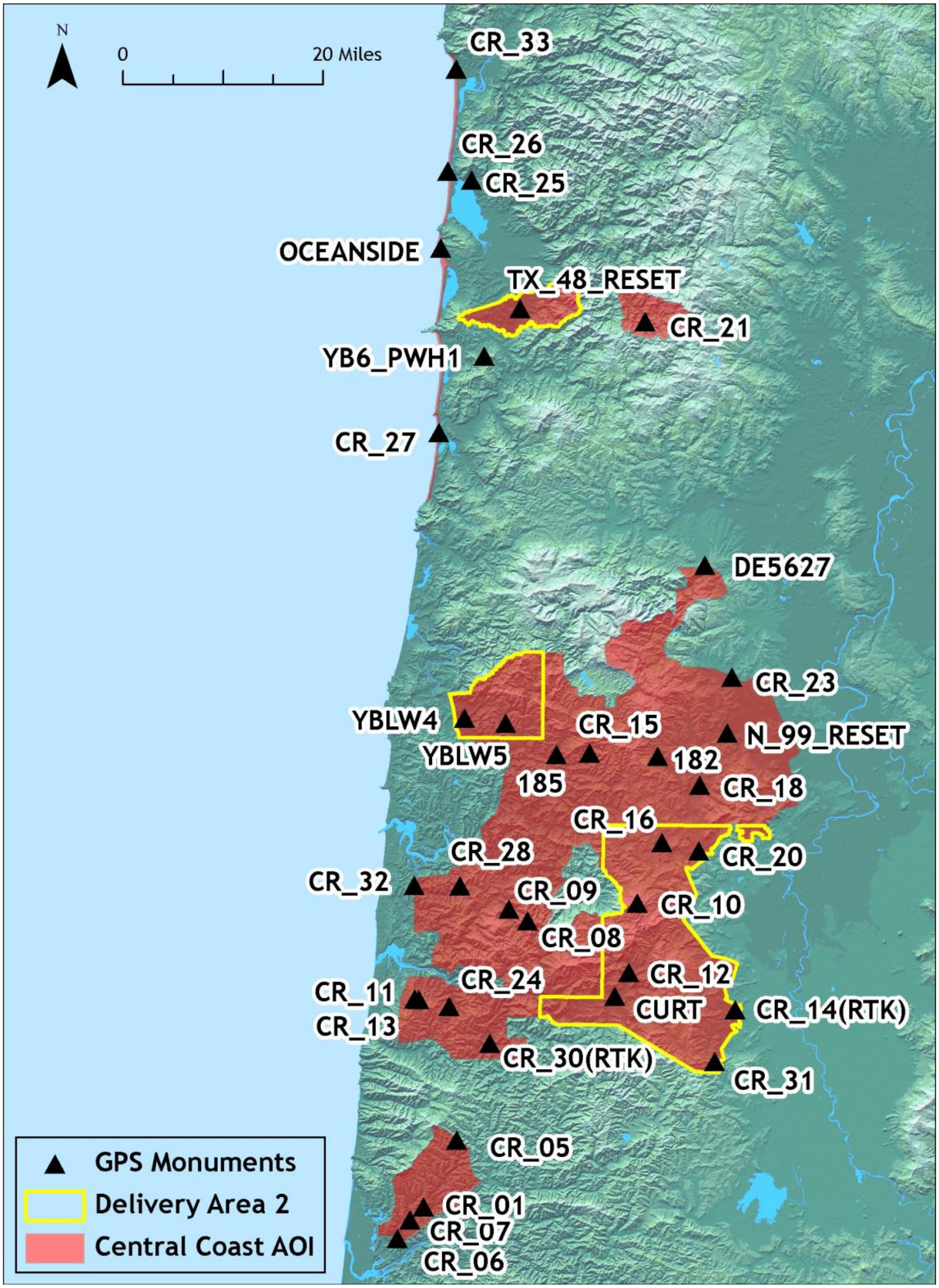
[5] Federal Geographic Data Committee Draft Geospatial Positioning Accuracy Standards

Table 2.2. *Base Station Surveyed Coordinates, (NAD83/NAVD88, OPUS corrected) used for kinematic post-processing of the aircraft GPS data for the Coast Range Study Area.*

	Datum NAD83 (HARN)		GRS80
Base Stations ID	**Latitude (North)**	**Longitude (West)**	**Ellipsoid Height (m)**
CR_01	440404.8076	1235847.192	194.951
CR_05	440956.6989	1235452.967	250.368
CR_06	440118.3549	1240155.983	-17.851
CR_07	440255.7118	1240024.768	-12.3955
CR_08	442905.9162	1234635.476	530.074
CR_09	443004.889	1234851.199	327.815
CR_10*	443043.8896	1233317.065	1097.26
CURT*	442236.4556	1233556.124	65.6445
CR_11	442211.6368	124010.5746	427.625
CR_12*	442440.0164	1233415.525	91.524
CR_13	44228.88445	1235940.267	407.438
CR_14(RTK)*	442129.5604	1232121.04	70.086
CR_15	444345.9538	1233911.937	174.406
CR_16*	443559.7537	1233018.36	163.796
CR_18	444101.682	1232544.149	96.249
YBLW4*	444640.773	1235432.049	-1.5735
YBLW5*	444616.7363	1234929.33	57.052
CR_20*	443517.0506	1232548.787	129.216
N_99_RESET	444533.5114	1232226.115	53.356
182	444330.5838	1233054.095	107.472
185	444336.3118	1234316.866	55.0985
CR_21	452120.4142	1233249.378	293.325
CR_23	445026.6211	1232152.517	54.596
DE5627	450009.7508	1232516.946	117.568
TX_48_RESET*	452224.0338	1234815.104	18.037
CR_24	442133.1705	1235600.306	140.962
CR_25	453333.4913	1235422.393	-17.9335
CR_26	453418.3859	1235720.652	-16.8515
YB6_PWH1	451813.25	1235235.049	246.589
CR_27	451132.1119	1235802.547	-15.9355
CR_28	443205.3535	1235450.488	267.105
CR_30(RTK)	441824.5682	123512.6469	36.084
CR_31*	441657.7733	1232346.943	289.828
CR_32	443203.5027	1240023.201	84.253
OCEANSIDE	452736.3845	1235805.915	14.39
CR_33	454311.5389	1235627.377	-13.775

***Delivery Area 2 GPS monument**

Figure 2.2. *Base stations for the Central Coast Study Area.*



For data delivered to date 5,758 RTK (Real-time kinematic) points were collected in the study area. **Figures 2.3 and 2.4** shows detailed views of selected RTK locations for the area delivered to date.

Figure 2.3. *Selected RTK point locations in the study area for delivery area 2; images are NAIP orthophotos.*

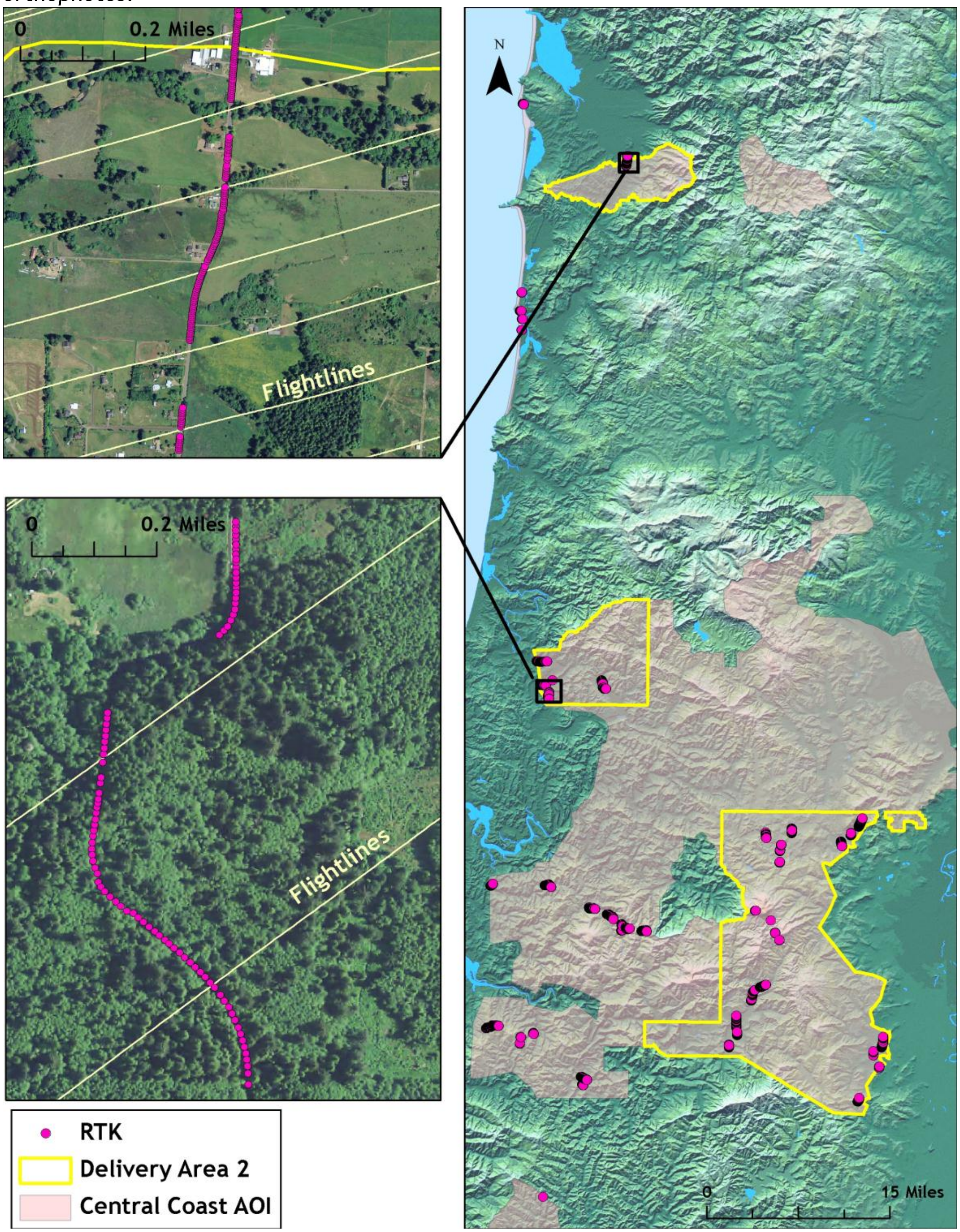
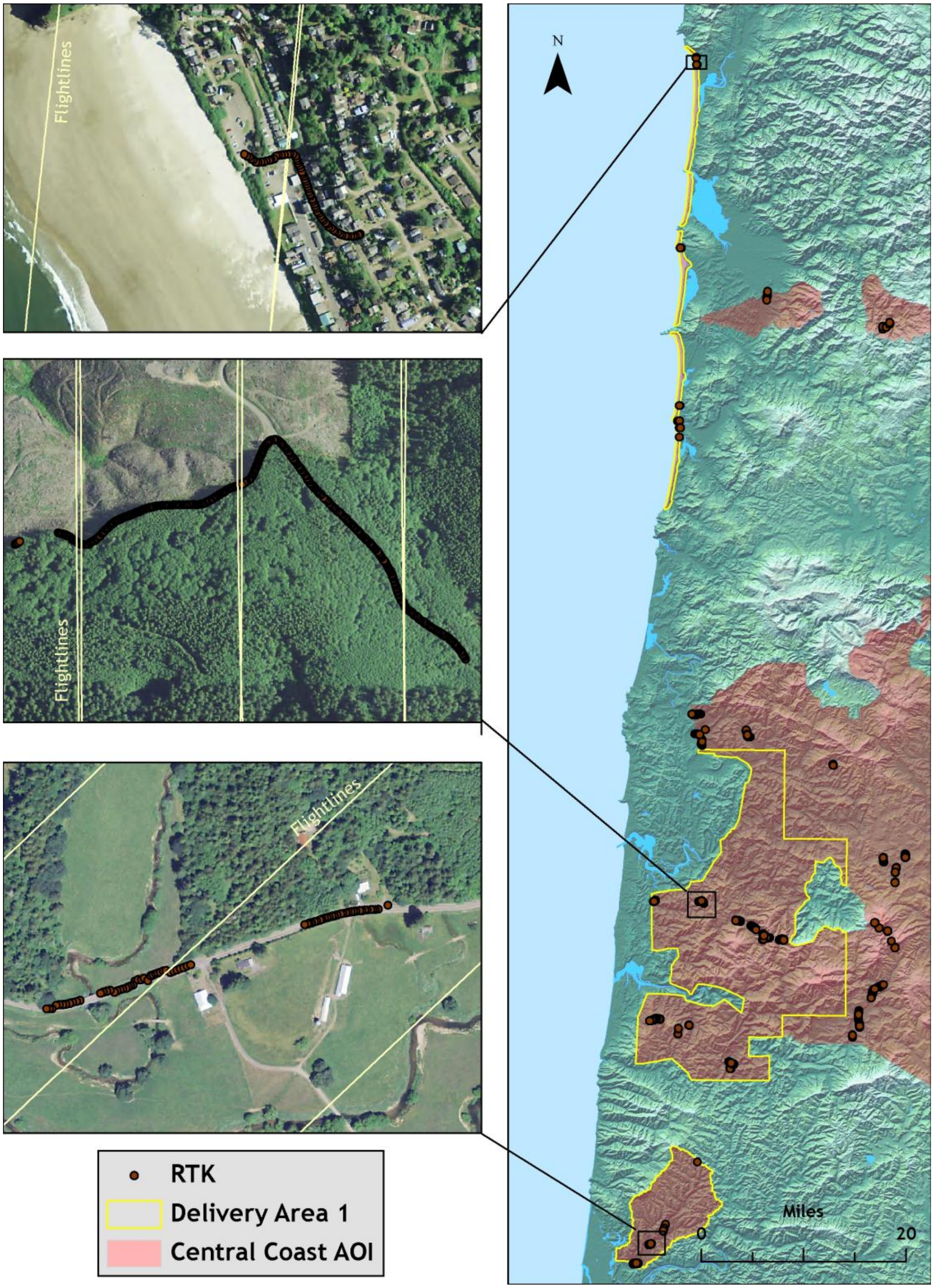


Figure 2.4. *Selected RTK point locations in the study area for delivery area 1; images are NAIP orthophotos.*



3. Accuracy

3.1 Relative Accuracy

Relative Accuracy Calibration Results

Relative accuracy refers to the internal consistency of the data set and is measured as the divergence between points from different flightlines within an overlapping area. Divergence is most apparent when flightlines are opposing. When the LiDAR system is well calibrated the line to line divergence is low (<10 cm). Internal consistency is affected by system attitude offsets (pitch, roll and heading), mirror flex (scale), and GPS/IMU drift.

Relative accuracy statistics shown in **Figures 3.2 and 3.3** are based on the comparison of 1406 flightlines and over 11 billion points. Relative accuracy is reported for the portion of the study area shown in **Figure 3.1** below.

- Project Average = 0.34 ft (0.10 m)
- Median Relative Accuracy = 0.31 ft (0.10 m)
- 1σ Relative Accuracy = 0.37 ft (0.11 m)
- 2σ Relative Accuracy = 0.62 ft (0.19 m)

Figure 3.1. *Relative Accuracy Covered Area.*

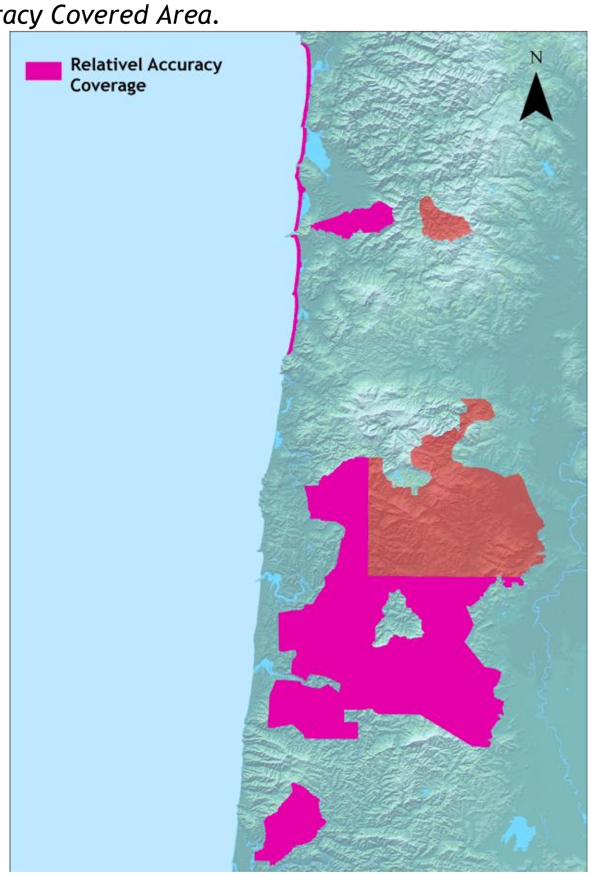


Figure 3.2. *Statistical relative accuracies, non slope-adjusted.*

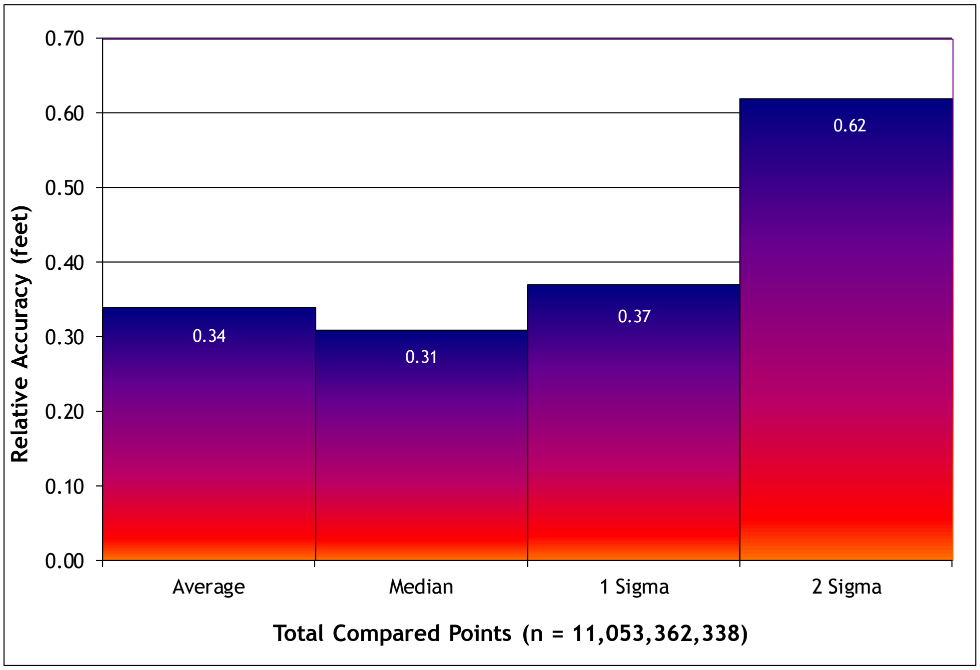
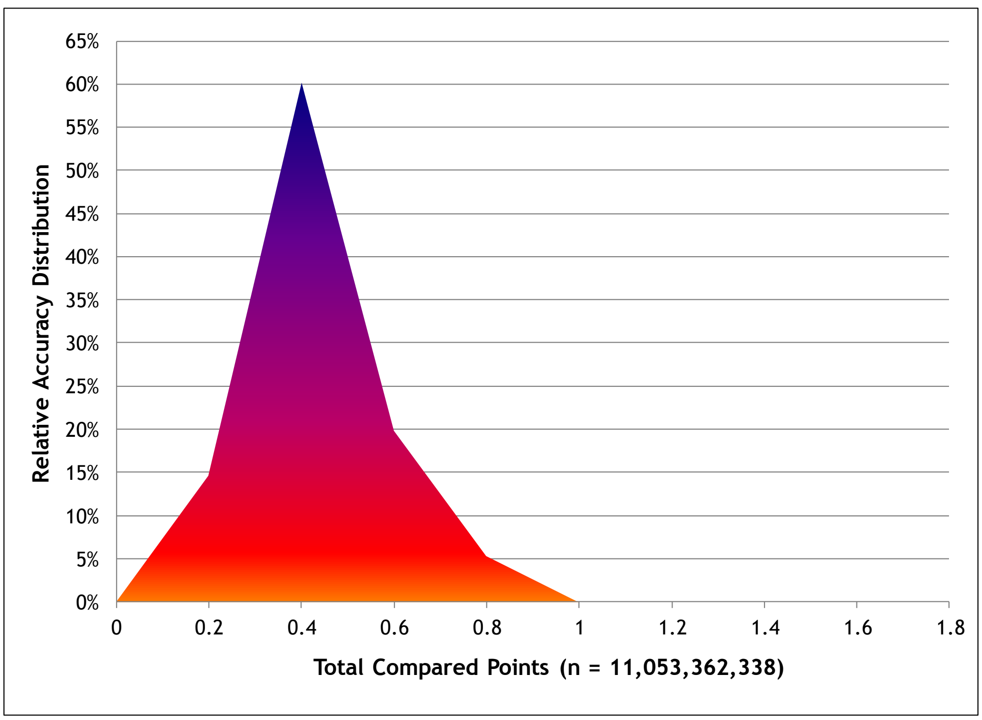


Figure 3.3. *Percentage distribution of relative accuracies, non slope-adjusted.*



3.2 Fundamental Vertical Accuracy

FVA accuracy reporting is designed to meet guidelines presented in the National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998). FVA compares known RTK ground survey points to the closest laser point. FVA uses ground control points in open areas where the LiDAR system has a "very high probability" that the sensor will measure the ground surface and is evaluated at the 95% percentile of $RMSE_{Z.}$ For the Central Coast Study Area, 5,758 RTK points were collected for data delivered to date.

For this project, no independent survey data were collected, nor were reserved points collected for testing. As such, vertical accuracy statistics are reported as "Compiled to Meet," in accordance with the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2004). Fundamental Vertical accuracy is reported for the portion of the study area shown in **Figure 3.4** and reported in **Table 3.1** below. Histogram and absolute deviation statistics are reported in **Figures 3.5 and 3.6**.

Table 3.1. *Fundamental Vertical Accuracy – Deviation between laser points and RTK survey points.*

Sample Size (n): 5,758	
Root Mean Square Error (RMSE): 0.17 ft (0.05 m)	
Fundamental Vertical Accuracy: Compiled to Meet 0.33 ft. (0.10m) fundamental vertical accuracy at 95% confidence level (1.96 x $RMSE_Z$) in open terrain	
Standard Deviations	**Deviations**
1 sigma (σ): 0.15 ft (0.05 m)	**Minimum Δz: -**0.84 ft (-0.26 m)
2 sigma (σ): 0.40 ft (0.12 m)	**Maximum Δz:** 0.46 ft (0.14 m)
	Average Δz: -0.07 ft (-0.02m)

Figure 3.4. *Absolute Accuracy Covered Area.*

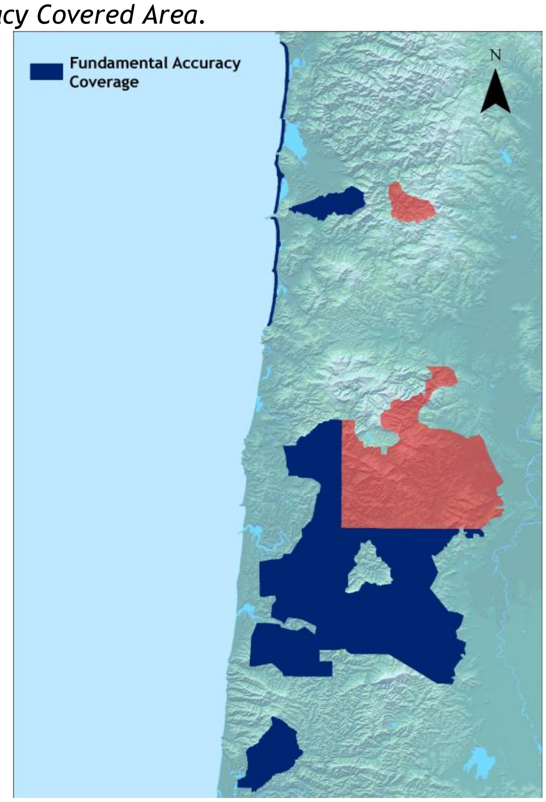


Figure 3.5. *Central Coast Range Study Area fundamental accuracy histogram statistics*

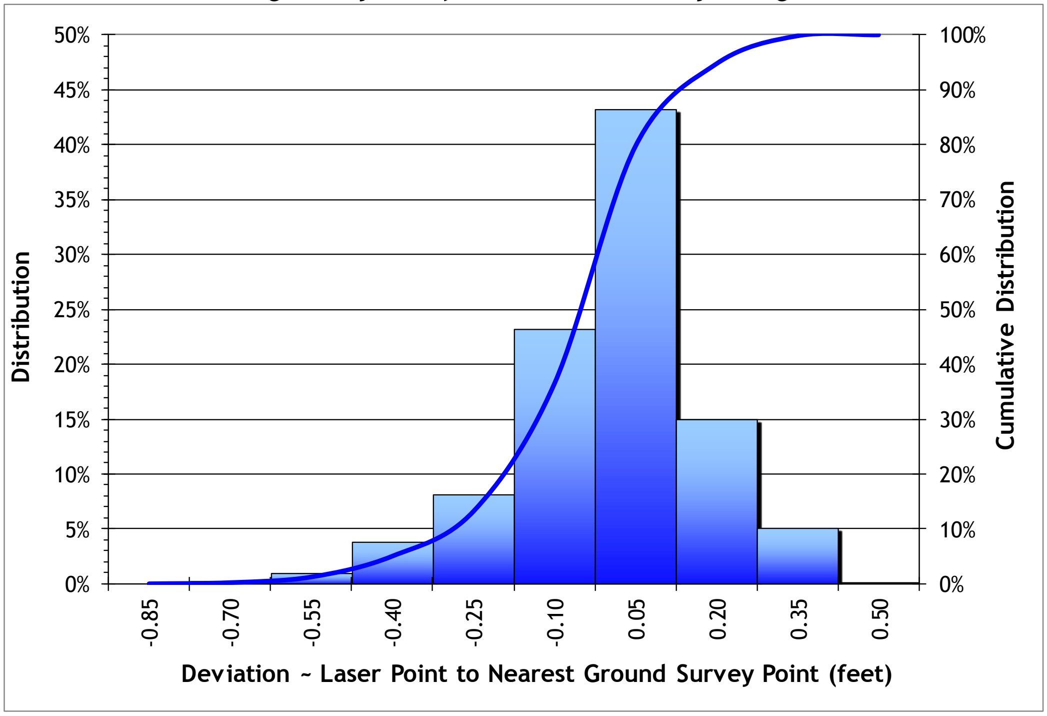
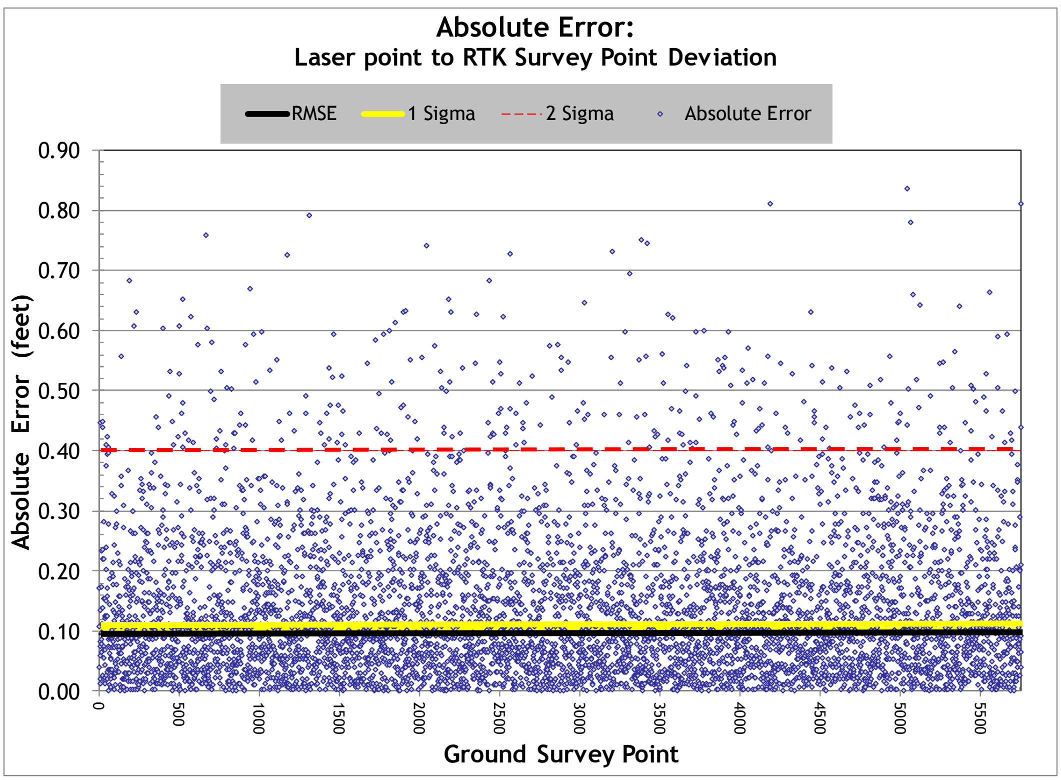


Figure 3.6. *Central Coast Range Study Area point absolute deviation statistics.*



3.2.1 Supplemental Vertical Accuracy by Land Cover

In addition to the hard surface RTK data collection, check points were also collected across the project area on four different land cover types to provide Supplemental Vertical Accuracy (SVA) statistics in accordance with NSSDA guidelines. All data collection was completed by WSI. As such, SVA statistics are reported as "Compiled to meet" in accordance with the ASPRS Guidelines Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2004).

The dominant land cover classes within the present project area are listed below. The descriptions provide further detail regarding the actual vegetation. This analysis demonstrates that the vertical accuracy of the interpolated ground surface, across all land cover classes, meets or exceeds vertical accuracy specifications.

Fallow:	Cropland, seasonally dormant or unplanted
Grass - short:	Grasses (<2 feet in height)
Grass - tall:	Grasses (>2 feet in height)
Shrub:	Woody vegetation (<6 feet in height)
Bare Earth:	Low grasses, plowed fields, lawns
Forest:	Fully covered by trees

Examples of selected land cover classes sampled with RTK.

Fallow

Grass - short

Grass - tall

Shrub

Tables 3.2a and **3.2b** detail summary statistics and reporting for SVA survey data by land cover class for the Central Coast study area. **Figure 3.7** illustrates the distribution of absolute deviation statistics by land cover type for land cover RTK survey data.

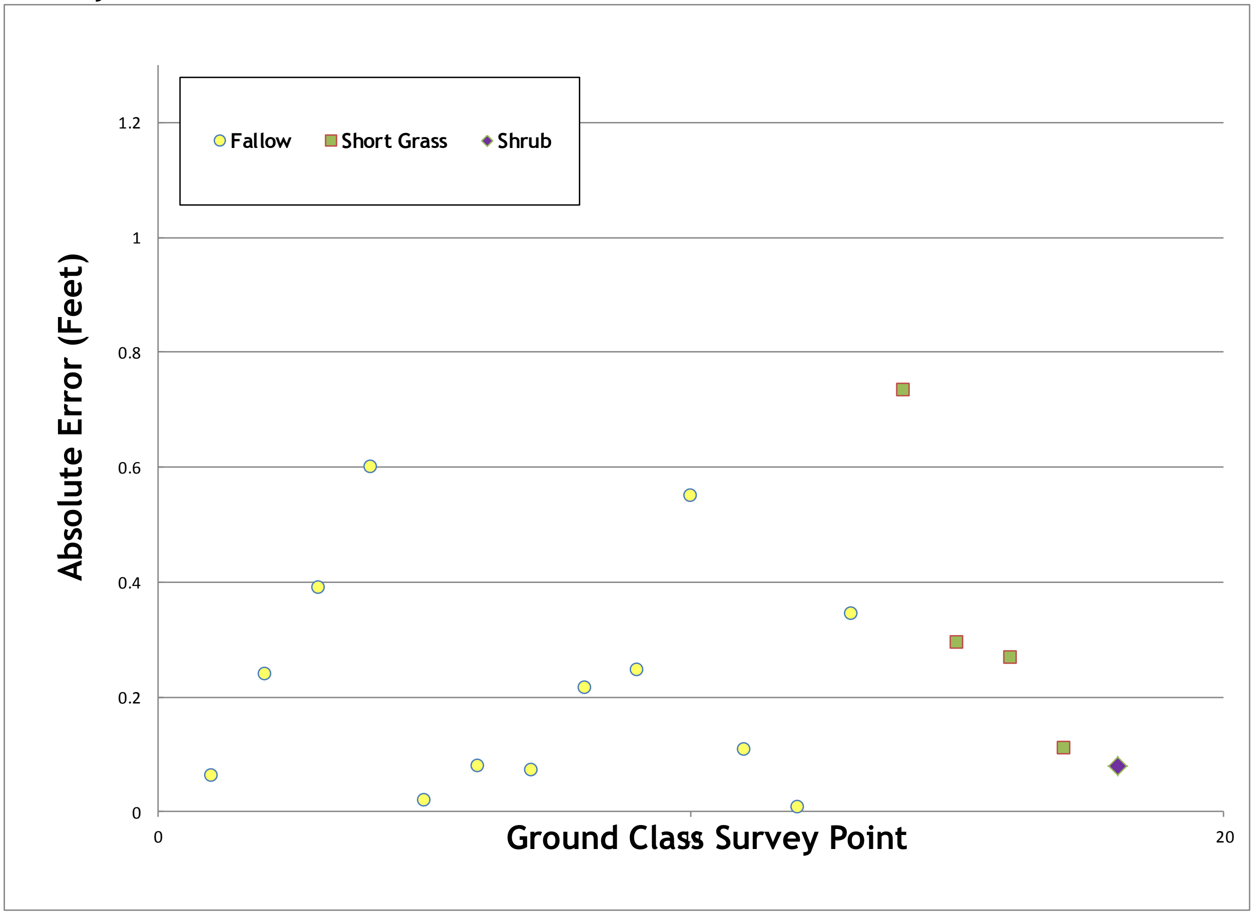
Table 3.2a. *Summary statistics for Supplemental Vertical Accuracy by land cover class.*

Land cover	Sample size (n)	RMSE: Ft (m)	Ave Dz :	1 sigma (σ):	2 sigma (σ) 95th %:
Fallow	13	0.29 ft. (0.09 m)	-0.11 ft. (-0.04 m)	0.25 ft. (0.08 m)	0.57 ft. (0.17 m)
Forest	4	0.42 ft. (0.13 m)	-0.22 ft. (-0.07 m)	0.30 ft. (0.09 m)	0.67 ft. (0.20 m)
Shrub	1	0.08 ft. (0.02 m)	0.08 ft. (0.02 m)	0.08 ft. (0.02 m)	0.08 ft. (0.02 m)

***Table 3.2b**. Supplemental Vertical Accuracy Reporting*

Category	Report
SVA (Fallow)	Compiled to meet 0.57 ft. (0.17 meters) supplemental vertical accuracy at 95th percentile in category: fallow
SVA (Forest)	Compiled to meet 0.67 ft. (0.20 meters) supplemental vertical accuracy at 95th percentile in category: grass – short
SVA (Shrub)	Compiled to meet 0.08 ft. (0.02 meters) supplemental vertical accuracy at 95th percentile in category: shrub

Figure 3.7. *Absolute deviation values by land cover class survey points used in Supplemental Vertical Accuracy assessment.*



4. Data Density/Resolution

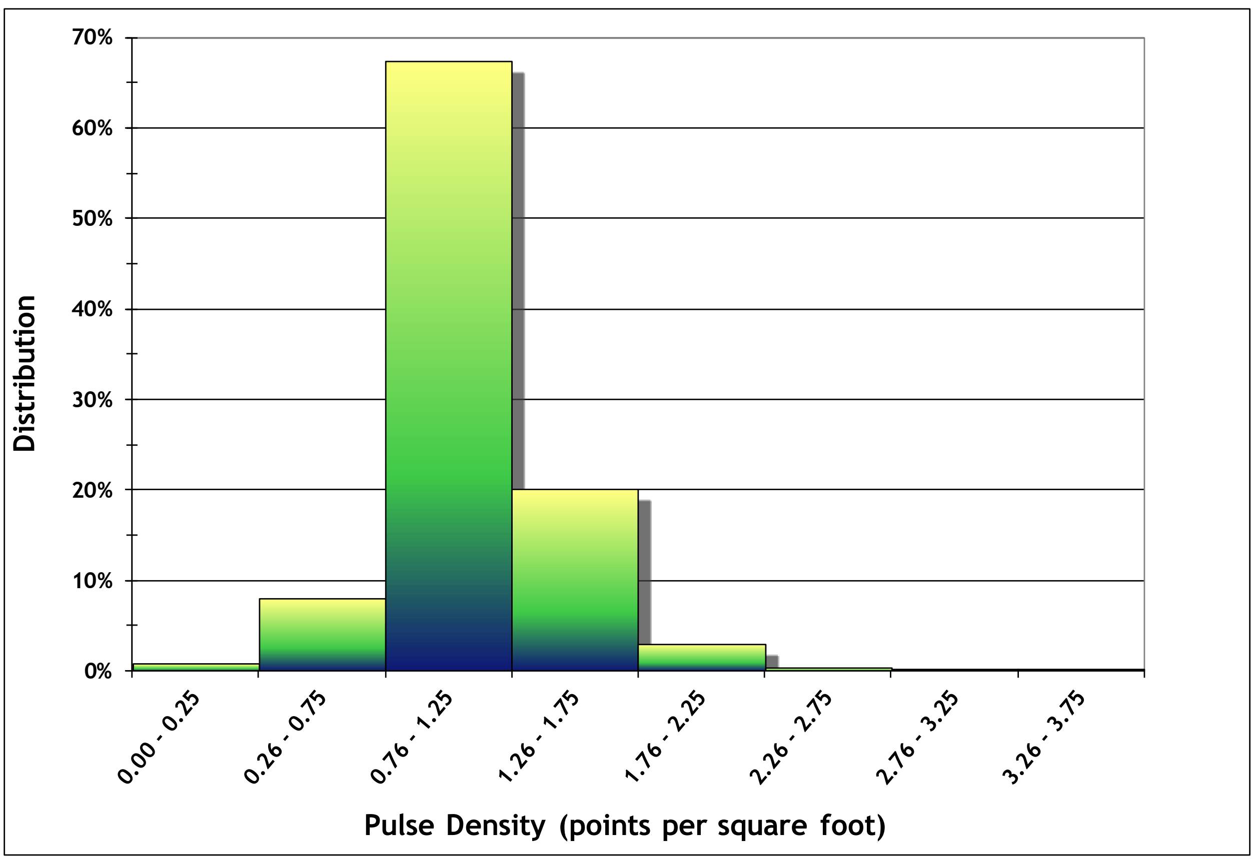
Density Statistics

Some types of surfaces (i.e. dense vegetation or water) may return fewer pulses than the laser originally emitted. Therefore, the delivered density can be less than the native density and vary according to terrain, land cover and water bodies. Density histograms and maps (**Figures 4.1 – 4.4**) have been calculated based on first return laser point density and ground-classified laser point density.

Table 4.1. *Average density statistics for Central Coast Study Area data delivered to date.*

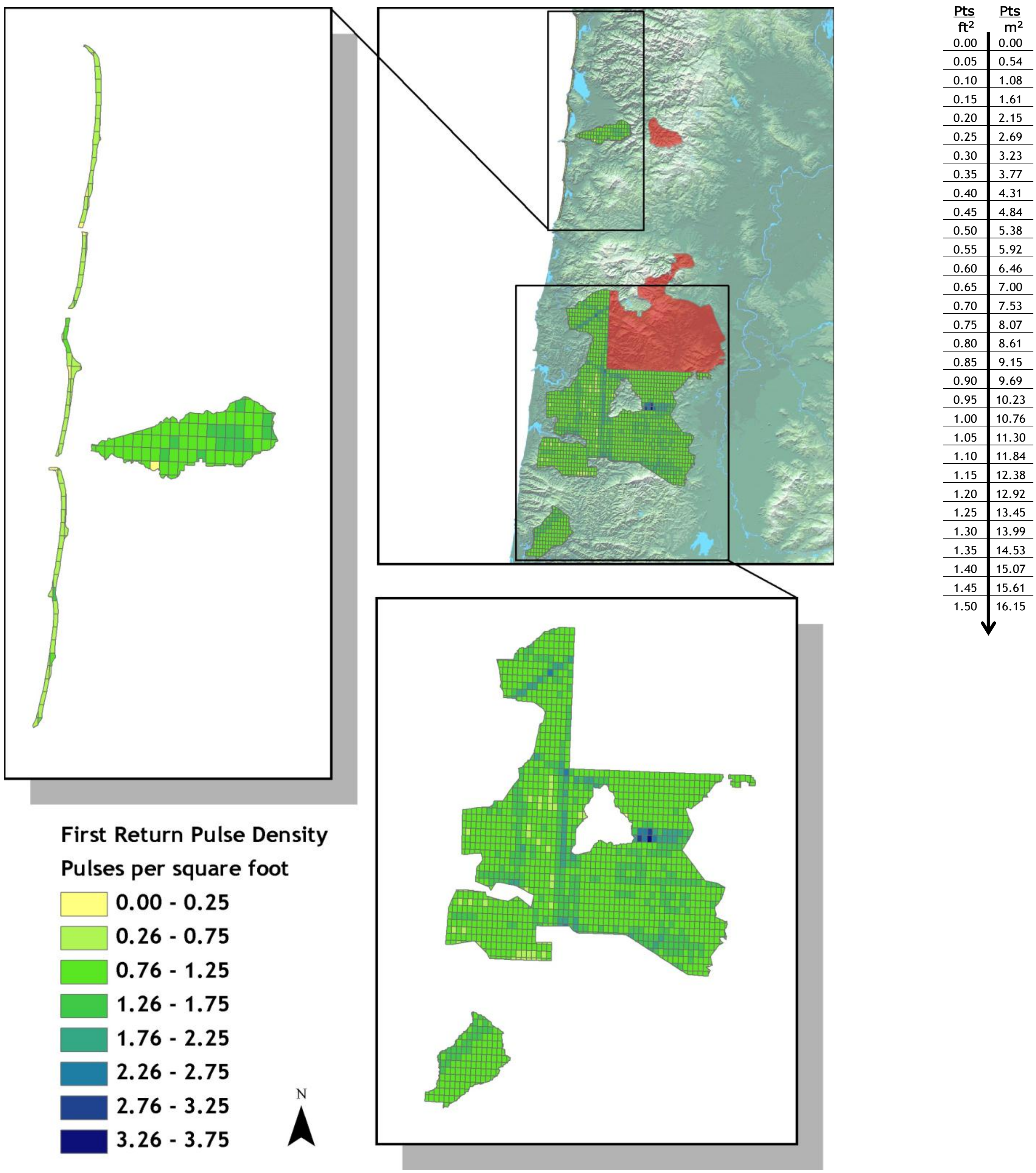
Average Pulse Density (per square ft)	Average Pulse Density (per square m)	Average Ground Density (per square ft)	Average Ground Density (per square m)
1.12	12.02	0.017	0.18

Figure 4.1. *Histogram of first return laser point density for data delivered to date.*



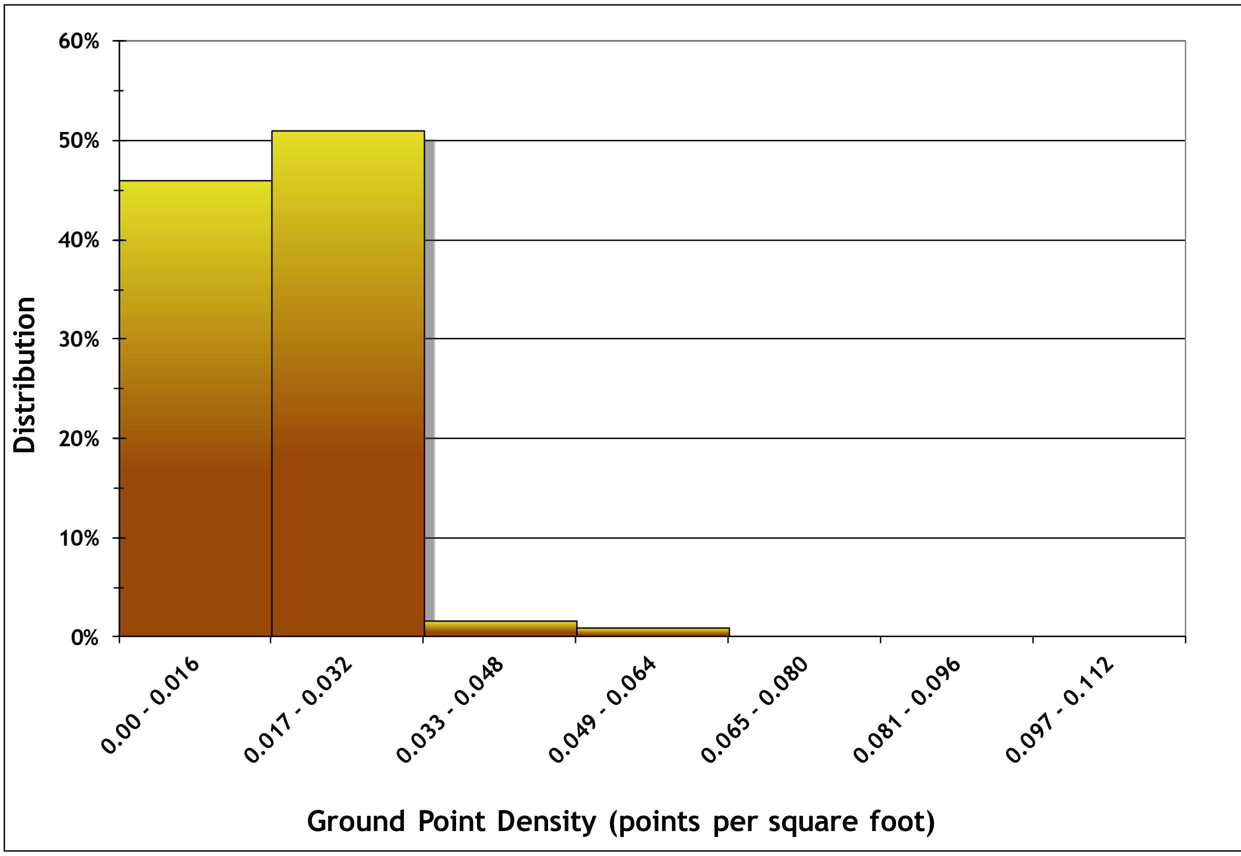
Pts ft²	Pts m²
0.00	0.00
0.05	0.54
0.10	1.08
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

Figure 4.2. *First return laser point densities per 0.75' USGS Quad for data delivered to date.*



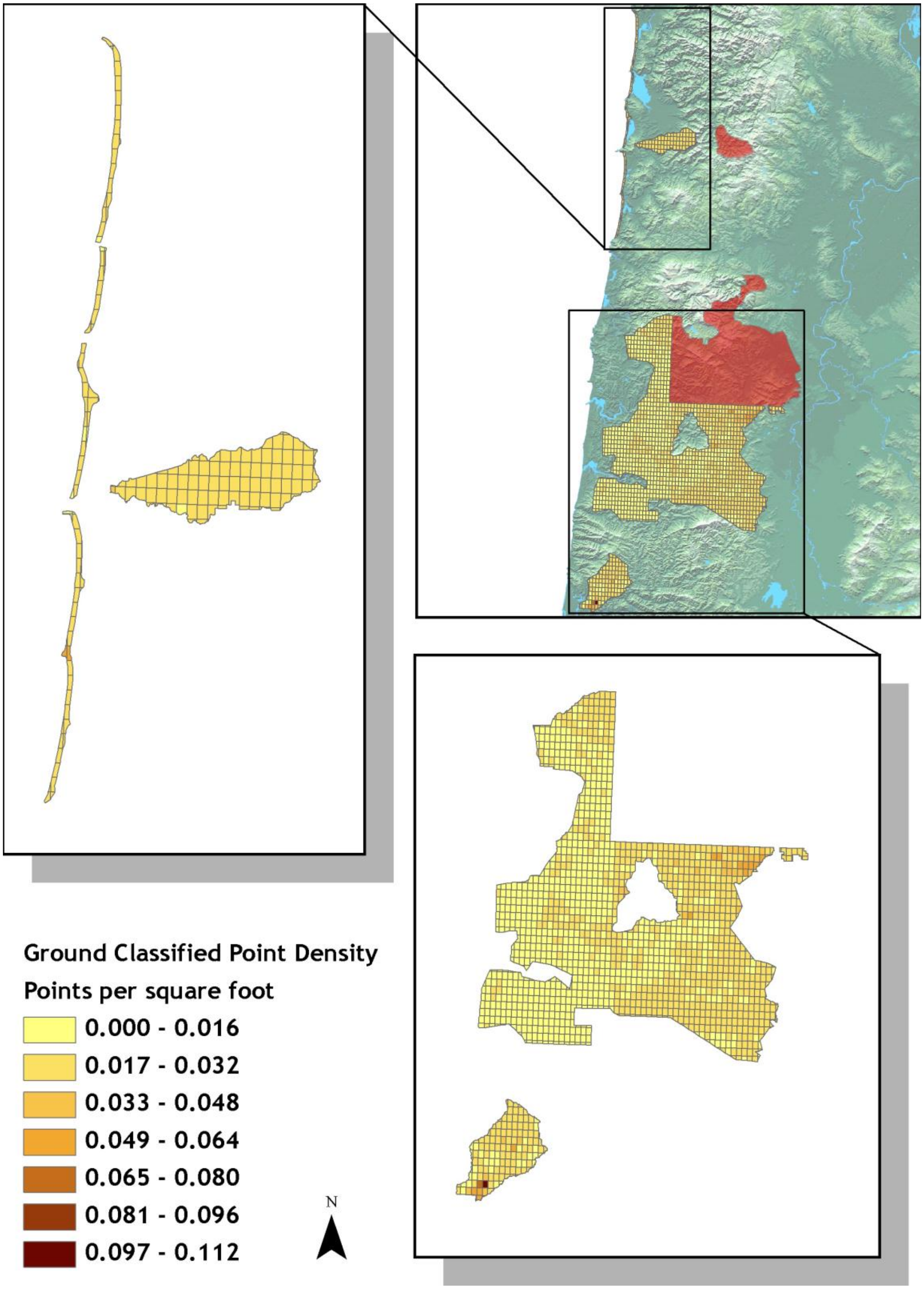
Ground classifications were derived from ground surface modeling. Classifications were performed by reseeding of the ground model where it was determined that the ground model failed, usually under dense vegetation and/or at breaks in terrain, steep slopes and at bin boundaries.

Figure 4.3. *Histogram of ground-classified laser point density for data delivered to date.*



Pts ft²	Pts m²
0.00	0.00
0.05	0.54
0.10	1.08
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

Figure 4.4. *Ground-classified laser point density per 0.75' USGS Quad for data delivered to date.*



Pts ft²	Pts m²
0.00	0.00
0.05	0.54
0.10	1.08
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

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5. Certifications

Watershed Sciences provided LiDAR services for the Central Coast study area as described in this report.

I, Mathew Boyd, have reviewed the attached report for completeness and hereby state that it is a complete and accurate report of this project.

Mathew Boyd
Principal
Watershed Sciences, Inc.

I, Christopher W. Yotter-Brown, being first dully sworn, say that as described in the Ground Survey subsection of the Acquisition section of this report was completed by me or under my direct supervision and was completed using commonly accepted standard practices. Accuracy statistics shown in the Accuracy Section have been reviewed by me to meet National Standard for Spatial Data Accuracy.

REGISTERED PROFESSIONAL LAND SURVEYOR 3/27/2012

OREGON
JULY 13, 2004
Christopher W. Yotter - Brown
60438 LS

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Christopher W. Yotter-Brown, PLS Oregon & Washington
Watershed Sciences, Inc
Portland, OR 97204

6. Citations

Federal Geographic Data Committee, 1998. Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy. Subcommittee for Base Cartographic Data, 25p.

Flood, M, (Ed.), 2004. ASPRS Guidelines-Vertical Accuracy Reporting for Lidar Data, V1.0. American Society for Photogrammetry and Remote Sensing (ASPRS) Lidar Committee, 20p.

7. Selected Imagery

Figure 7.1. *Neahkahnie Beach and Manzanita, Oregon. View to the South. Image is a three-dimensional LiDAR point cloud with RGB values extracted from a 2010 NAIP orthophoto.*

Figure 7.2. *Cape Lookout on Oregon coast, Tillamook County. View to the North. Image is a three-dimensional LiDAR point cloud with RGB values extracted from a 2010 NAIP orthophoto.*

Figure 7.3. *City of Logsden, Oregon and Highway 411, 15 miles NE of Newport, Oregon. View to the South. Image is a three-dimensional LiDAR point cloud with RGB values extracted from a 2010 NAIP orthophoto.*

Figure 7.4. *Oregon Coast Highway 101, eight miles south of Tillamook, Tillamook County. View to the East. Image is a three-dimensional LiDAR point cloud with RGB values extracted from a 2010 NAIP orthophoto.*

Figure 7.5. *Highway 34, two miles northeast of Alsea, Benton County. View to the North (Cover image). Image is a three-dimensional LiDAR point cloud with RGB values extracted from a 2010 NAIP orthophoto.*

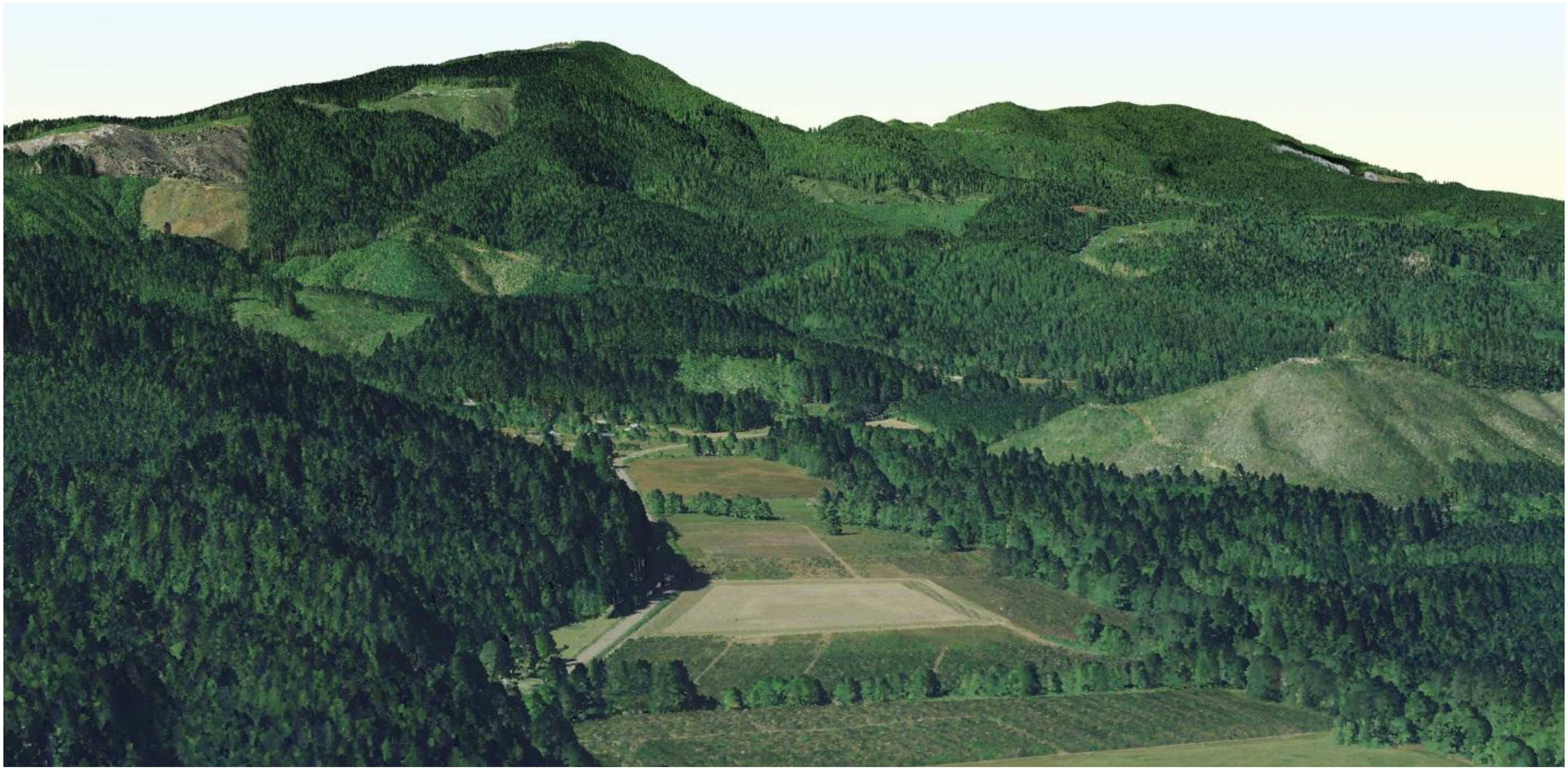

Figure 7.6. *View from atop Mary's Peak. Fifteen miles west of Corvallis, Benton County. View to the South. Image is a three-dimensional LiDAR point cloud with RGB values extracted from a 2010 NAIP orthophoto.*