



Exploring Spatial Patterns of Overflights at Bryce Canyon National Park



Main Amphitheater, Bryce Canyon National Park
NPS/TYRA OLSTAD

Exploring spatial patterns of overflights at Bryce Canyon National Park

Science Report NPS/SR—2024/149

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Abstract

This study explored spatial patterns of overflights at Bryce Canyon National Park (BRCA). Overflights were analyzed from August 14, 2023 to March 12, 2024 using Automatic Dependent Surveillance-Broadcast (ADS-B) data. Phase 1 of analysis focused on all overflights and found airspace use was predominantly by commuter traffic along major flight paths. Phase 2 of analysis focused on low-level overflights that fly below 11,500 ft mean sea level (MSL) and fly within 10-miles of the BRCA boundary. It found that most flights occurred between 9,500–10,500 ft MSL. Flights below 8,500 ft MSL concentrated around the Bryce Canyon Airport just outside the park and the main scenic amphitheater within the park. Phase 3 of analysis removed all overflights that were civil patrol flights, major airlines, and survey flights. The remaining flights were low-level overflights, including air tours. Kernel density analysis revealed that these flights were most concentrated in the northwest corner of the park at an altitude interval of was 501–1,000 ft above ground level (AGL). The greatest percentage of flights were between 1,500–2,000 ft AGL, clustered over the main amphitheater and Fairyland / Tropic Ditch. Midday was the most popular time of day for overflights. Two thirds of the flights were by fixed-wing single engine aircraft, with relatively few rotorcraft. This information can be used for planning and management purposes, as well as a resource and baseline for future research.

List of Acronyms

AGL: Above ground level

ADS-B: Automatic Dependent Surveillance-Broadcast

BRCA: Bryce Canyon National Park

DEM: Digital Elevation Model

FAA: Federal Aviation Administration

GIS: Geographic information systems

MSL: Mean sea level

NPS: National Park Service

Introduction

The purpose of this report is to examine the spatial patterns of all overflights at Bryce Canyon National Park (BRCA), which may assist in the management and communication between air tour operators, other airspace users, and the park.

Home to one of the most colorful and unique landscapes in the National Park Service—a rim of orange, pink, and white limestone eroding into the world’s largest concentration of delicate rock spires called “hoodoos”—BRCA was designated as a national monument in 1923 and became a national park in 1928.

More than two million people visit the park each year, most to see the main amphitheater—a bowl-shaped headwall containing iconic hoodoos such as Thors Hammer and Silent City. East-facing overlooks at Sunrise Point, Sunset Point, Inspiration Point, and Bryce Point afford spectacular views, particularly at dawn, when the sun’s rays illuminate the hoodoos and highlight features such as natural windows and arches, as well as at sunset, when the last of the day’s light lingers on the distant Aquarius Plateau. Many visitors also follow the entire 18-mile scenic drive, stopping at viewpoints such as Paria View, Farview, Natural Bridge, and Yovimpa Point. The busiest months are between June and September, with January and February least-visited. During the summer, visitors can stay overnight at one of two developed campgrounds or at the Bryce Canyon Lodge, all near the main amphitheater.

The western half of the park perches atop the Paunsaugunt Plateau, up to an elevation of 9,115 feet Mean Sea Level (MSL) (2,778 meters) at Rainbow Point at the southern end. The eastern half of the park falls into the drainages below, with a low elevation of 6,620 feet MSL (2,018 meters) at Yellow Creek, southeast of Paria View. Several trails switchback down into the hoodoos, most popularly: Queen’s Garden and Navajo Loop in the main amphitheater; and Fairyland, which connects to another bowl north of Boat Mesa. Another extremely popular trail ambles to Mossy Cave and Tropic Ditch Falls directly from Highway 12. Much of the area below the rim—including Fairyland and a section north of Highway 12, but excluding the main amphitheater, Tropic Ditch and Mossy Cave—is Recommended Wilderness, making up approximately 58% of the park (20,810 acres of a total 35,835) (Figure 1 and Figure 2). The wilderness area features a 23-mile long Under the Rim Trail as well as shorter connecting trails and loop trails and contains 10 backcountry campsites.

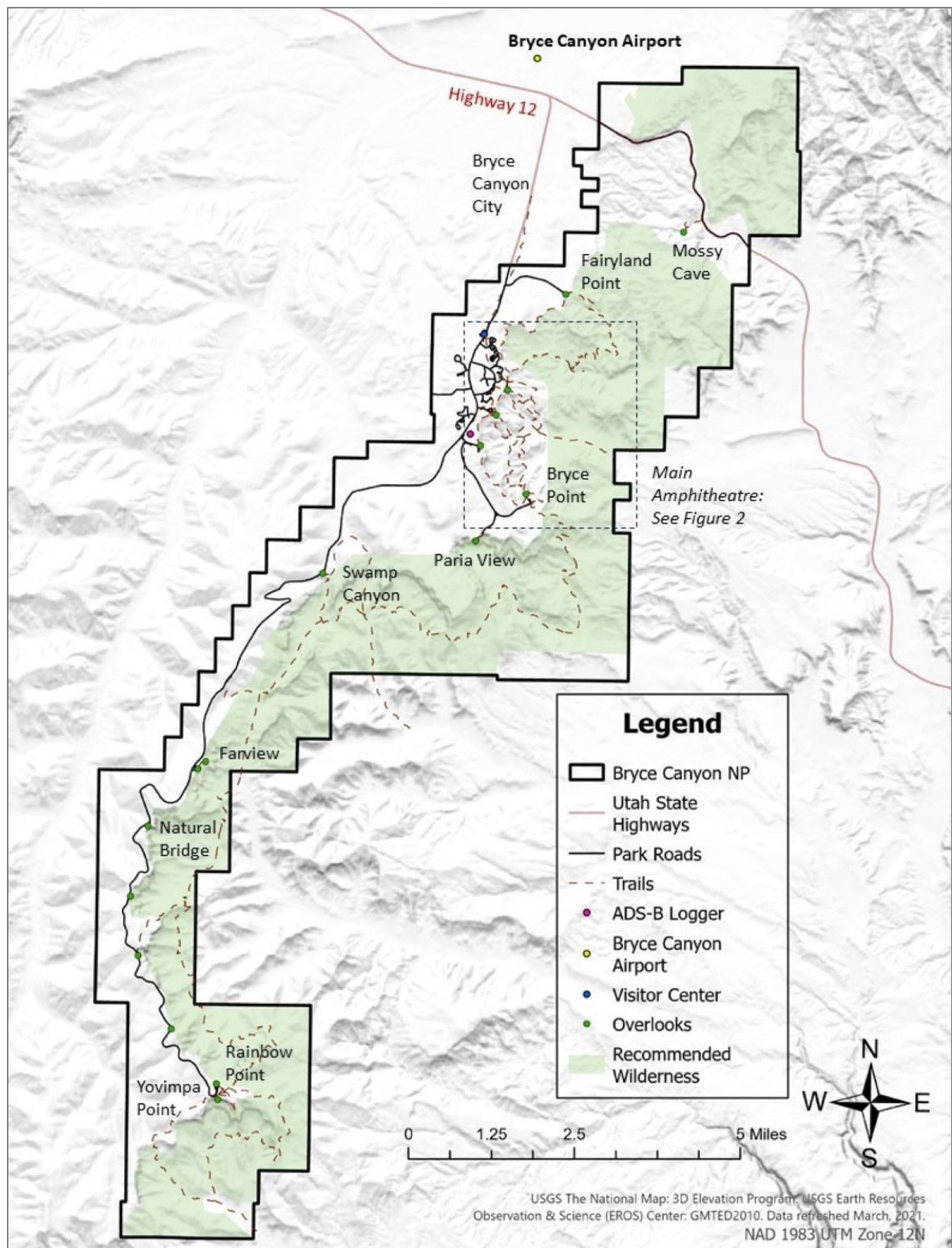


Figure 1. Generalized map of Bryce Canyon National Park.

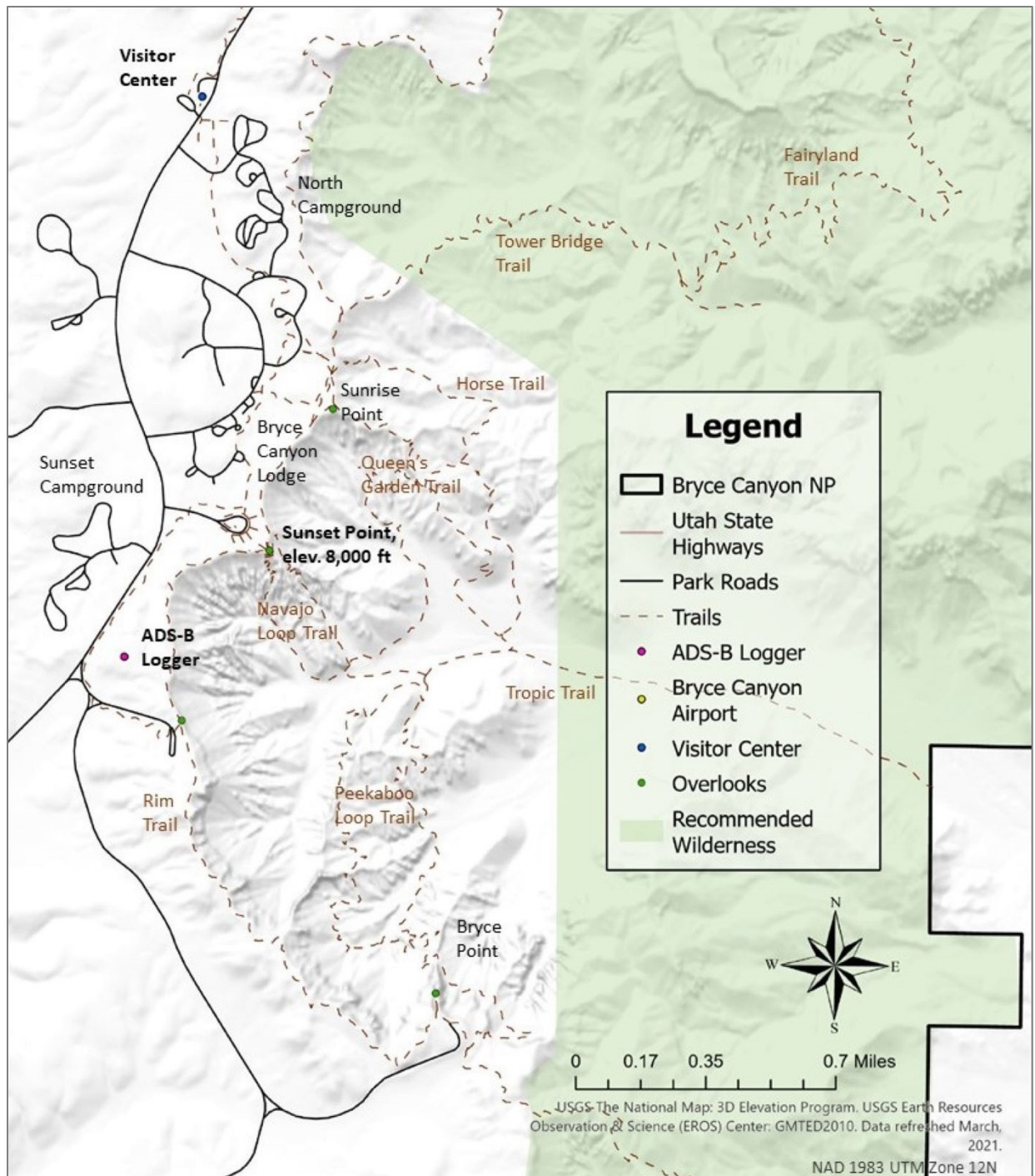


Figure 2. Trails, overlooks, and the location of the ADS-B logger at the main amphitheater, Bryce Canyon National Park.

In 2019 (the last year with pre-COVID data), there were 532 reported air tours conducted over BRCA by 6 authorized operators. Before the park's Air Tour Management Plan (ATMP) was finalized in October 2022, nine commercial air tour operators held interim operating authority to conduct a total of 3,131 commercial air tours over BRCA each year. The ATMP now in place

authorizes up to 515 air tours per year on defined routes conducted over the park and up to 0.5-mile outside the boundary. In addition to determining the number of air tours authorized per year, the ATMP designated specific air tour routes and altitudes (helicopters 9,250 feet MSL and fixed-wing aircraft 9,750 feet MSL—generally 1,500–2,600 feet above ground level (AGL) for helicopters and 2,000–2,600 AGL for fixed-wing aircraft, aside from a short segment in the south end of the park where the terrain is higher.) It also stipulated that air tours may only operate from one hour after sunrise until three hours before sunset, unless the aircraft operates with quiet technology (Figure 3).

As of January 1, 2020, the FAA requires all aircraft that enter designated airspace to be equipped with ADS-B technology (see 14 CFR § 91.225 and 14 CFR § 91.227) (FAA, 2023a). However, no airspace requires ADS-B technology over BRCA. Regardless of the airspace designation, prior studies suggest a rather ubiquitous adoption of ADS-B by aircrafts in the United States (Peterson et al., 2022; Peterson et al., 2023). ADS-B signals are transmitted from aircraft and provide location information and unique identifiers to improve airspace safety and air traffic efficiency (FAA, 2023b). This study analyzes aircraft using ADS-B technology that flew above BRCA between August 14, 2023 and March 12, 2024.

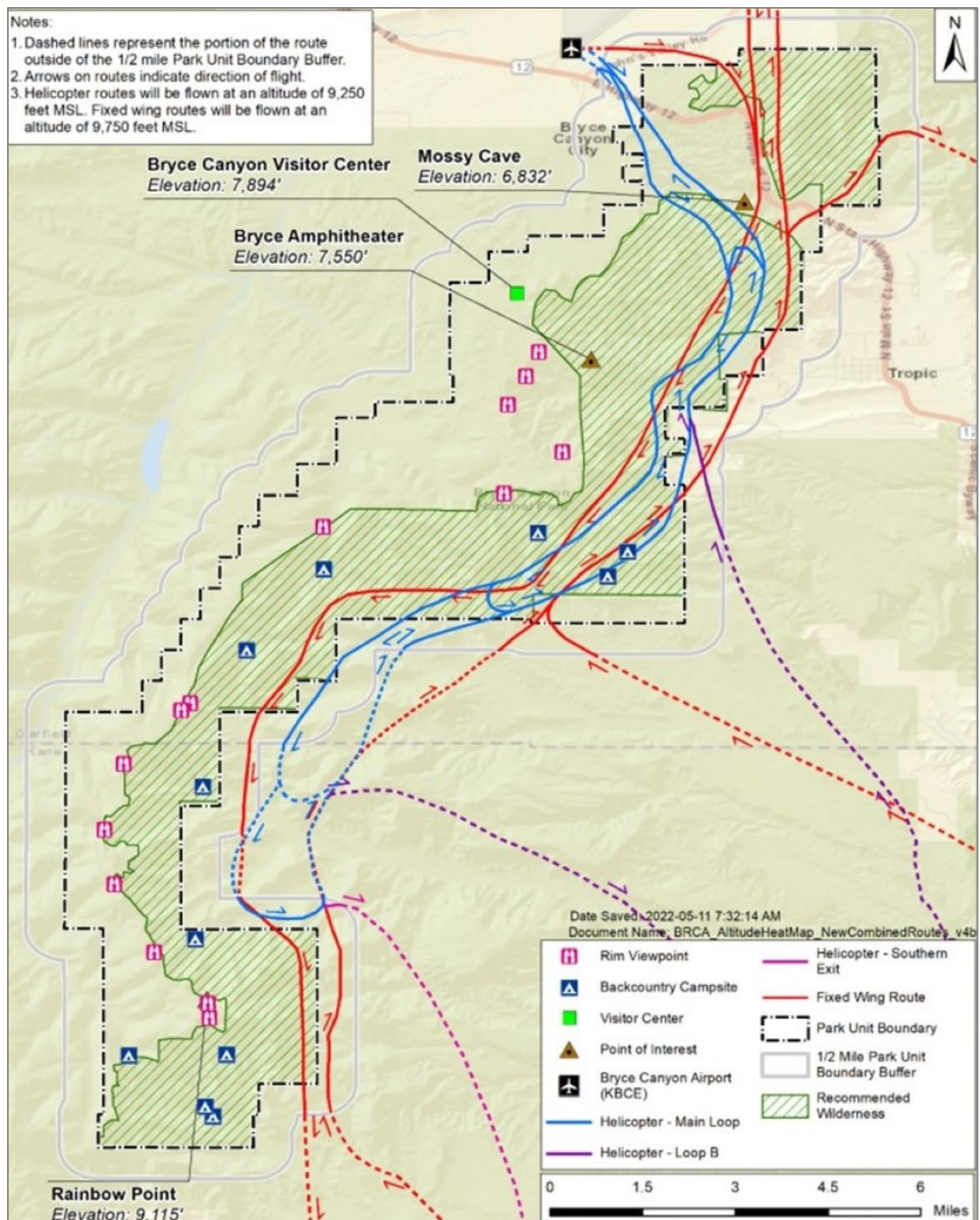


Figure 3. Commercial air tour routes over Bryce Canyon National Park. (Figure 2, p. 5 in the Final Air Tour Management Plan – Bryce Canyon National Park, Oct 2022).

Methods

Data Collection

Data were collected by an ADS-B data logger positioned with an unimpeded and expansive skyward exposure at Science Hill, near the main amphitheater. (See Figures 1 and 2). The logger recorded ADS-B signals as text files.

Data Processing and Cleaning

Data processing, cleaning, and analysis were accomplished using a custom ArcGIS Pro toolbox with multiple Python-based geoprocessing tools that automated and simplified processing and analysis of ADS-B data. The toolbox conducted the following tasks: processed raw ADS-B data files, removed repeated occurrences of waypoints collected by multiple data loggers, created waypoint and flightline feature classes (spatial reference = North American Datum 1983 Universal Transverse Mercator Zone 12N), merged daily waypoints and flightlines, screened for suspected flights known not to be air tours (discussed in the next paragraph), conducted kernel density analysis, summarized waypoint altitudes, summarized number of flights across several temporal scales (monthly, daily, hourly), and summarized number of flights across aircraft types (rotorcraft, fixed-wing single engine, fixed-wing multi-engine).

This report expresses altitude using mean sea level (MSL) and above ground level (AGL). Altitude expressed in MSL refers to the altitude of an aircraft above sea level, regardless of the terrain below it, whereas altitude expressed in AGL is a measurement of the distance between the ground surface and the aircraft. To calculate AGL altitudes for each waypoint, a 1/3 arc second 10-meter digital elevation model (DEM) was used (United States Geological Survey, 2024). The AGL altitudes were calculated by subtracting the reported altitudes of the ADS-B logger minus the elevation of the DEM for every point location (x,y) (see Beeco et al., 2020 for exact method).

ADS-B technology can use barometric altitude or geometric altitude. Barometric altitude is determined by measuring air pressure and must be regularly calibrated. Geometric altitude is calculated using the Global Positioning System (GPS). GPS is generally considered a more reliable and accurate measure, but the aviation industry has long used barometric altitudes during flight. Aircraft owners/operators determine which system to use on their aircraft. The analysis in this report does not attempt to correct for any error associated with altitude information, as this would be nearly impossible to determine. Therefore, calculations of AGL can in some cases be negative. This can occur for low flying aircraft that have an ADS-B system reporting an altitude lower than actual. Negative AGL calculations can also be due to an aircraft's ADS-B system malfunction. Further, the level of resolution in 10-meter DEM can introduce some error. Negative AGL values are reported in the analysis.

To explore spatial patterns of overflights at BRCA, analysis was conducted in three phases. Phase 1 is a visual examination of all overflights within 10 miles of the park. Phase 2 reports altitudes using MSL while Phase 3 uses AGL detailed to 0.5 mile beyond the park boundary. This is because MSL is better suited for understanding aircraft patterns across a larger space or scale because the baseline (sea level) does not change. However, because Phase 3 includes more detailed examinations of the

data, AGL analysis was used because it better contextualizes how flights fly over undulating terrain and associated terrestrial resources and visitors' experiences. All maps produced during analysis used Esri basemaps with service layer credits for: Esri, USGS, HERE, Garmin, SafeGraph, FAO, METI/NASA, and EPA; and all data were projected to North American Datum 1983 Universal Transverse Mercator Zone 12N.

Phase 1 Methods

The purpose of the first phase was to explore all overflight paths above BRCA regardless of flight type or altitude. Thus, the flightline feature class was not cleaned of any flight types. To understand how flightpaths extended beyond the park boundary, a 10-mile buffer around the BRCA boundary was used. One map was produced that showed all of the data, totaling 4,439 flights.

Phase 2 Methods

The purpose of the second phase was to understand low-level overflights above BRCA regardless of flight type. Similar to Phase 1, a 10-mile buffer was used. Low-level overflights were identified as having an altitude less than 11,500 ft MSL, or about 2,400 ft above the highest point in the park (9,115 ft at Rainbow Point). Flights at or below this altitude would have the greatest impact on the acoustic environment in the park. To understand flight altitudes, a waypoint feature class was used. Five maps were produced which show low-level overflight waypoints across the following MSL altitudes:

- 6,500–7,500 ft MSL: the lowest point in BRCA to the altitude of many of the hoodoos in the main amphitheater and Fairyland, as well as the Tropic Ditch region and the Highway 12 corridor below the rim;
- 7,501–8,500 ft MSL: approximately the bottom of the area below the rim to just a few hundred feet above the main northern viewpoints;
- 8,501–9,500 ft MSL: the altitude of the southern viewpoints to a few hundred feet above;
- 9,501–10,500 ft MSL: 2,000–3,000 feet above the areas under the rim;
- 10,501–11,500 ft MSL: 1,400–2,400 feet above the highest point in the park.

Phase 3 Methods

The purpose of the third phase was to remove flights known not to be air tours. The toolbox also joined ADS-B data to the FAA Releasable Database via aircraft unique identifiers to determine aircraft tail number, type registrant (e.g., government), and engine type. Using this information along with ADS-B data, the toolbox screened for suspected flights known not to be air tours by cleaning the data of: 1) civil patrol flights, 2) major airlines, 3) straight-line flights, 4) flights with a flightpath less than a mile in length, and 5) survey flights. Civil patrol flights were identified as government aircraft (FAA Releasable Database type registrant = 5). Major airlines were identified using a list of major airlines (e.g., American Airlines, Delta Airlines, Southwest Airlines) inputted into the Python-based tool. Straight-line flights were assessed by calculating sinuosity values, which was used to identify any major airlines that were not listed in the prior step. Sinuosity is a measure of how much a linear feature deviates from a straight-line condition and can be calculated as the ratio of total flight path length to the straight-line distance between a flight's initial and final waypoint. A perfectly

straight flight path would have a sinuosity of one, but as the number of meanders in the path increases (e.g., the characteristic back and forth of survey flight behavior) sinuosity will begin to approach zero. All overflights that received sinuosity values greater than or equal to 0.99 were visually inspected to validate straight-line paths were flown and these were subsequently removed from analysis. Flights less than a mile in length were removed due to data integrity issues. Lastly, survey flights were removed from analysis because of their undue influence on analysis, infrequent nature, and known flight purpose. Survey flight behavior can be identified when a flight route consists of consecutive back and forth lateral movements in a parallel progression. Conversely, air tour behavior generally consists of flight routes that veer toward sightseeing locations and consist of sporadic S-turns and loops (Beeco & Joyce, 2019). After this cleaning step, the remaining flights are more likely to be air tours, but many flights represent recreational pilots, charter flights, or other low-level flight paths.

Consistent with other aircraft tracking reports, a 0.5-mile buffer around the park was used for Phase 3 to understand spatial patterns of low-level overflights that likely have the biggest influence on BRCA's acoustic environment. Using a 500 ft AGL altitude interval, waypoint data were segmented up to 5,000 ft AGL and kernel density analysis was conducted for each altitude interval. Kernel density is a type of spatial analysis that calculates the density of features—in this case, waypoints—in a unit area (square kilometers) around each raster cell, using a distance-weighted kernel surface to account for the distance features within a raster cell's unit area are from the cell. Resulting heat maps help visualize where the waypoints are concentrated within each altitude interval. Kernel density outputs can also be statistically compared, using a correlation test via the 'Band Collection Statistics' tool.

However, visualizations using the raw data only display patterns within each particular altitude interval. They are not comparable to one another in terms of overall density values because each altitude interval had a different number of waypoints and different maximum density values. To normalize density classifications across altitude intervals and compare patterns across all altitudes, the altitude interval with the highest maximum density of waypoints was used to determine a standard density classification, breaking the maximum number of points per square kilometer into five equal intervals. These classification intervals were then applied to the other altitude intervals, to ensure density was calculated the same across altitude intervals regardless of the number of waypoints.

Next, four figures were produced to spatially compare AGL and MSL waypoint trends. The first two figures display waypoint altitudes between 0–2,500 ft AGL and 2,501–5,000 ft AGL using a 500 ft AGL interval classification. The park's low point of 6,620 feet MSL and high point of 9,115 feet MSL were used to design the next two figures: one of waypoint altitudes between 6,620–9,000 ft MSL and the fourth figure displays waypoint altitudes between 9,001–11,500 ft MSL.

Quantitative analyses further characterize waypoint frequencies across AGL and MSL intervals; number of flights across months, day of the week, and hour of the day; and number of flights across aircraft types.

Lastly, to gain insight into overflight travel patterns across aircraft types, four figures were produced to visualize flightpaths for fixed-wing aircraft (single engine and multi-engine), rotorcraft, and aircraft that did not transmit identifying data via their onboard ADS-B units (recorded as “null” values). Aircraft known to belong to permitted commercial air tour operators, based on the tail numbers and registration, were also identified and mapped.

Results

Results — Phase 1

The research team mapped overflights for all flights ($n=4,439$). Areas with more concentrated opaque lines indicate where there is greater flight density. Figure 4 reveals the general pattern of airspace utilization above Bryce Canyon. Only a few condensed traffic routes occur over the park, the most prevalent of which is the travel corridor between Denver and Las Vegas that cuts directly over the southern part of the park, near Rainbow Point.

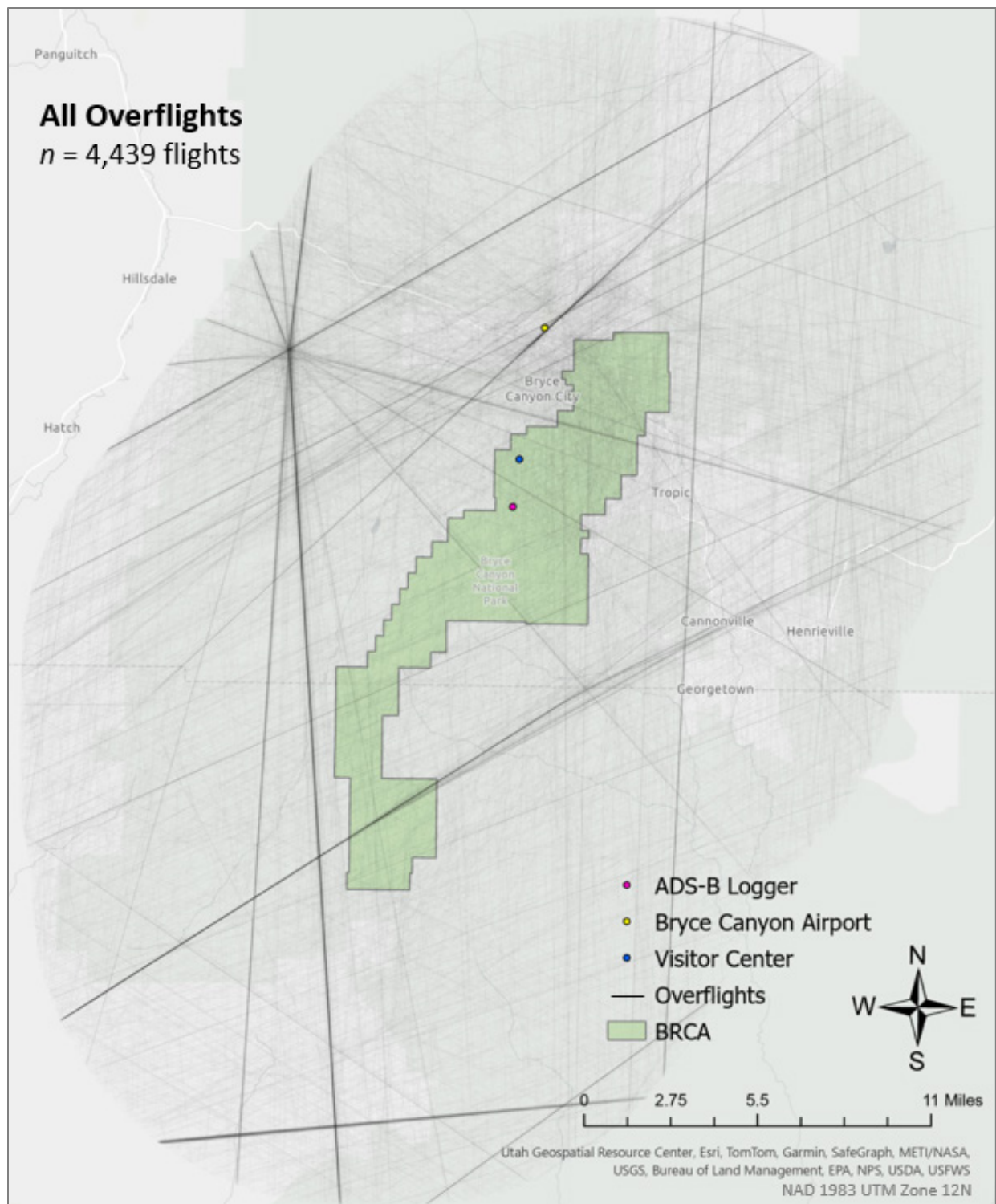


Figure 4. All Overflights, BRCA.

Results — Phase 2

The research team mapped waypoints for all overflights that flew between 6,500–12,500 feet MSL (377,727 total waypoints), which is displayed across four figures: 6,500–7,500 feet MSL (11,501 waypoints); 7,501–8,500 feet MSL (65,562 waypoints); 8,501–9,500 feet MSL (84,709 waypoints); 9,501–10,500 feet MSL (120,094 waypoints); and 10,501–11,500 feet MSL (95,861 waypoints). (Figures 5–9.) These show that the number of waypoints increase with altitude, with the greatest number of flights between 9,500–10,500 MSL. There are very few flights below 7,500 MSL, mostly aircraft lifting off from the Bryce Canyon Airport or circling low in the main amphitheater.

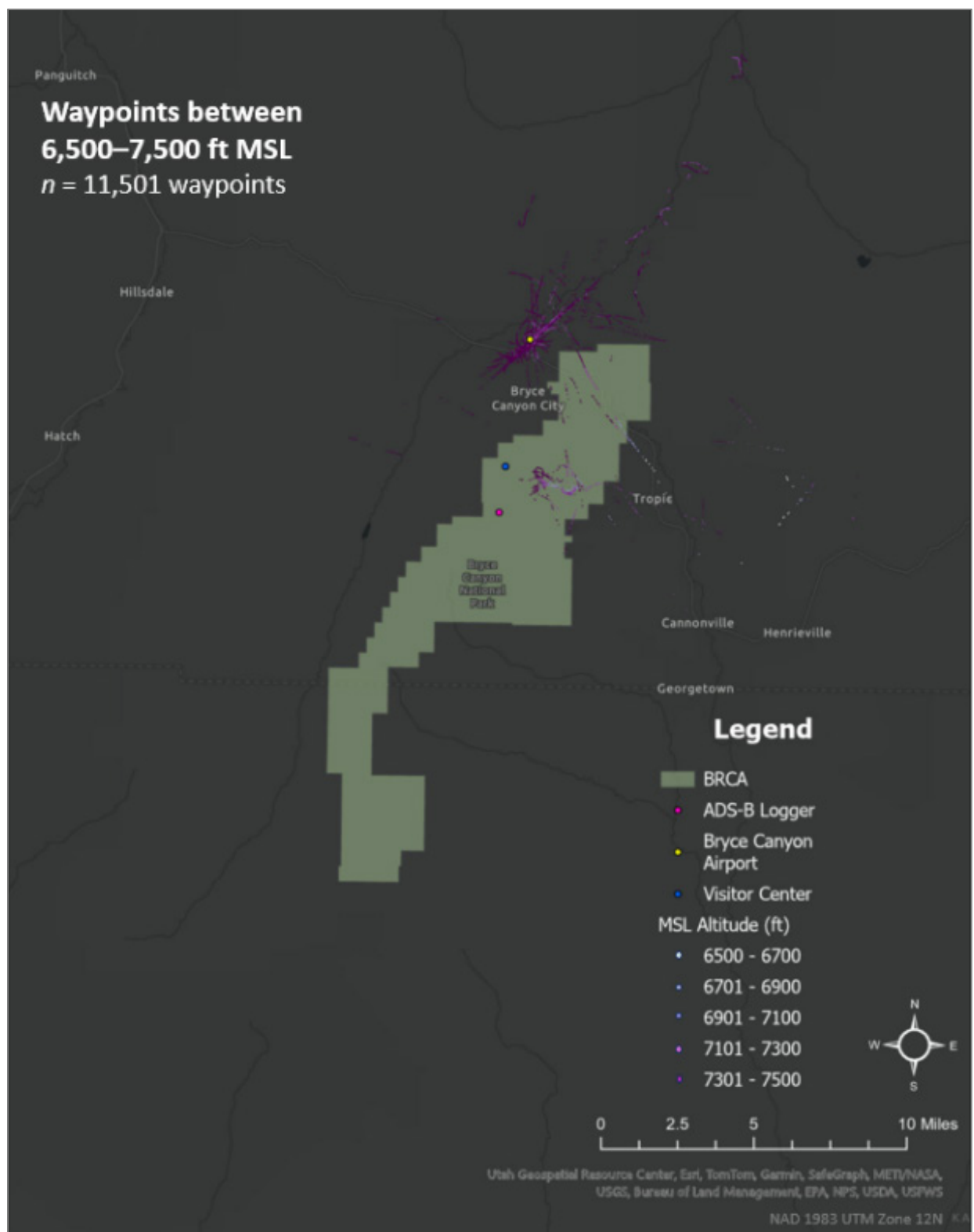


Figure 5. Waypoints over BRCA between 6,500–7,500 ft MSL.

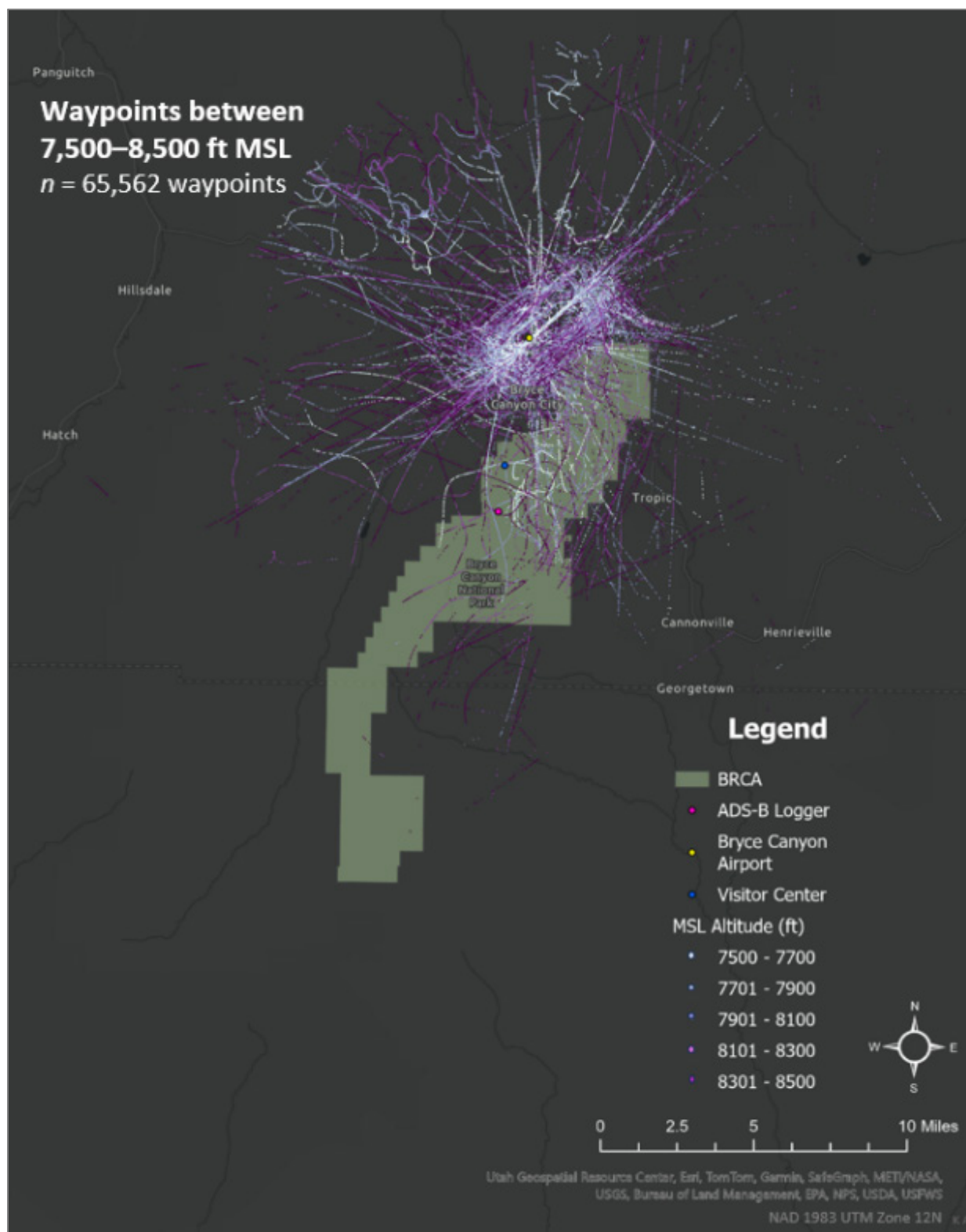


Figure 6. Waypoints over BRCA between 7,500–8,500 ft MSL.



Figure 7. Waypoints over BRCA between 8,500–9,500 ft MSL.



Figure 8. Waypoints over BRCA between 9,500–10,500 ft MSL.

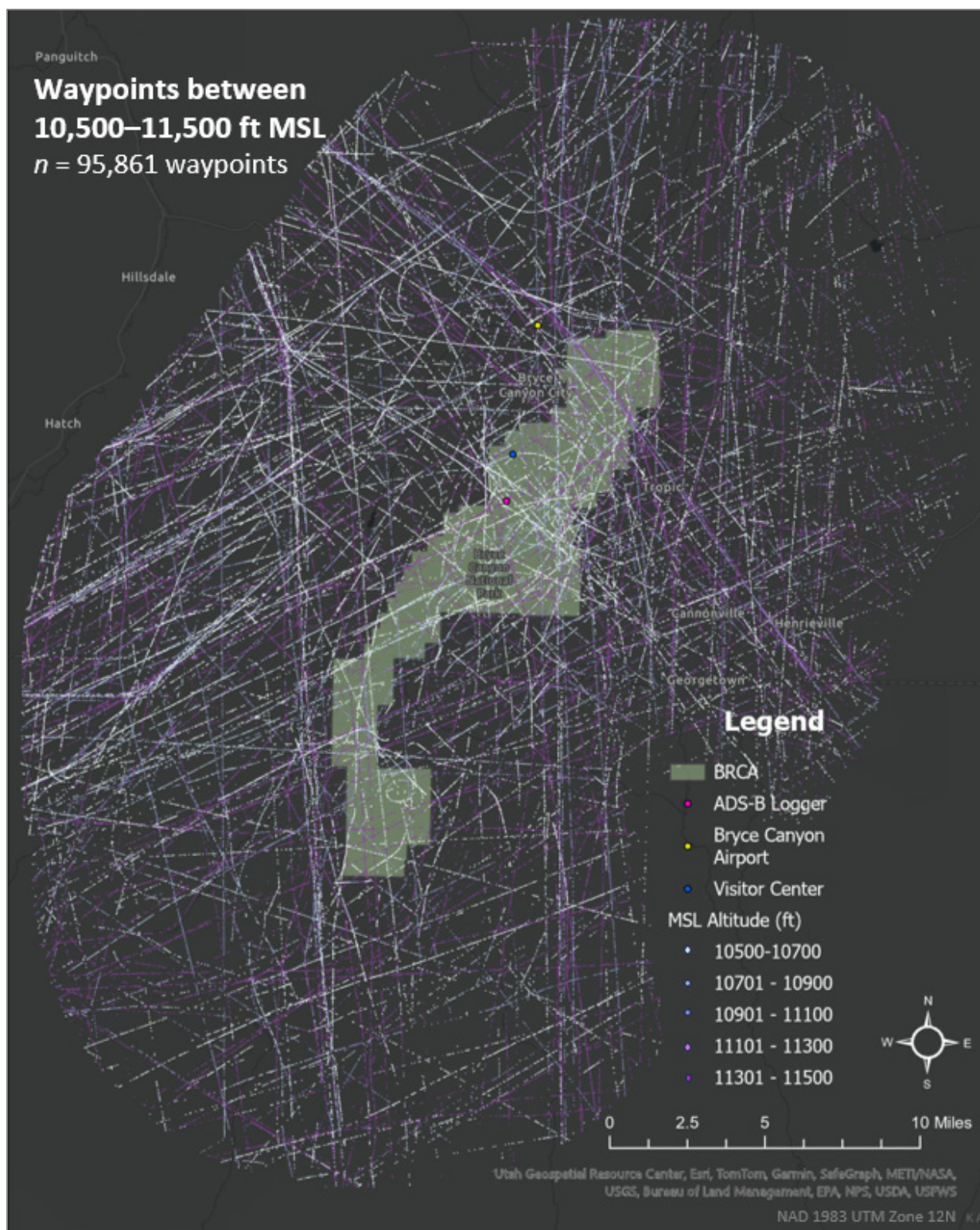


Figure 9. Waypoints over BRCA between 10,500–11,500 ft MSL.

Results — Phase 3

Data were cleaned of all flights known not to be air tours, leaving 2,273 flights remaining. The following numbers of flights were removed: 169 civil patrol flights, 1,847 straight-line flights, 3 flights with a flightpath less than a mile in length, 0 survey flights, and 147 commercial airline flights. (Note: most of the commercial airline flights were likely removed during the cleaning of straight-line flights). When the waypoints for these flights were clipped to a 0.5-mile boundary of BRCA, the number of separate flightlines increased slightly, to 2,298. This is likely due to the shape of BRCA's boundary; flights heading northeast or southwest may cross over the portions of the park around Agua Canyon and Yellow Creek, leaving and re-entering the 0.5-mile buffer in between. A difference of 25 flightlines only represents 1.1% of the data.

Using this dataset, kernel density analysis was conducted across AGL altitude intervals of 500 feet up to 4,501–5,000 ft AGL for a non-normalized analysis and normalized analysis. Figure 10 displays non-normalized heat maps for the most relevant altitude intervals, 0–3,500 ft AGL, with each altitude level visualized based on a different maximum number of points per square kilometer. This indicates a transition from very concentrated, very low flights near the Bryce Canyon Airport climbing to or descending from to a more widely distributed, higher elevation flights over the main amphitheater and Paria View / Yellow Creek. Dense low-level overflights were not found above 3,500 ft AGL.

For the normalized analysis, the altitude interval that showed the most density was 501–1,000 ft AGL. This density altitude was then used as the baseline to normalize the other altitude ranges. Figure 11 compares normalized density hot spots for 0–3,500 ft AGL across 500 ft altitude intervals, zoomed in to the northern portion of the park. This reveals that across the entire area within 0.5 miles of the park, flights are most concentrated near the airport.

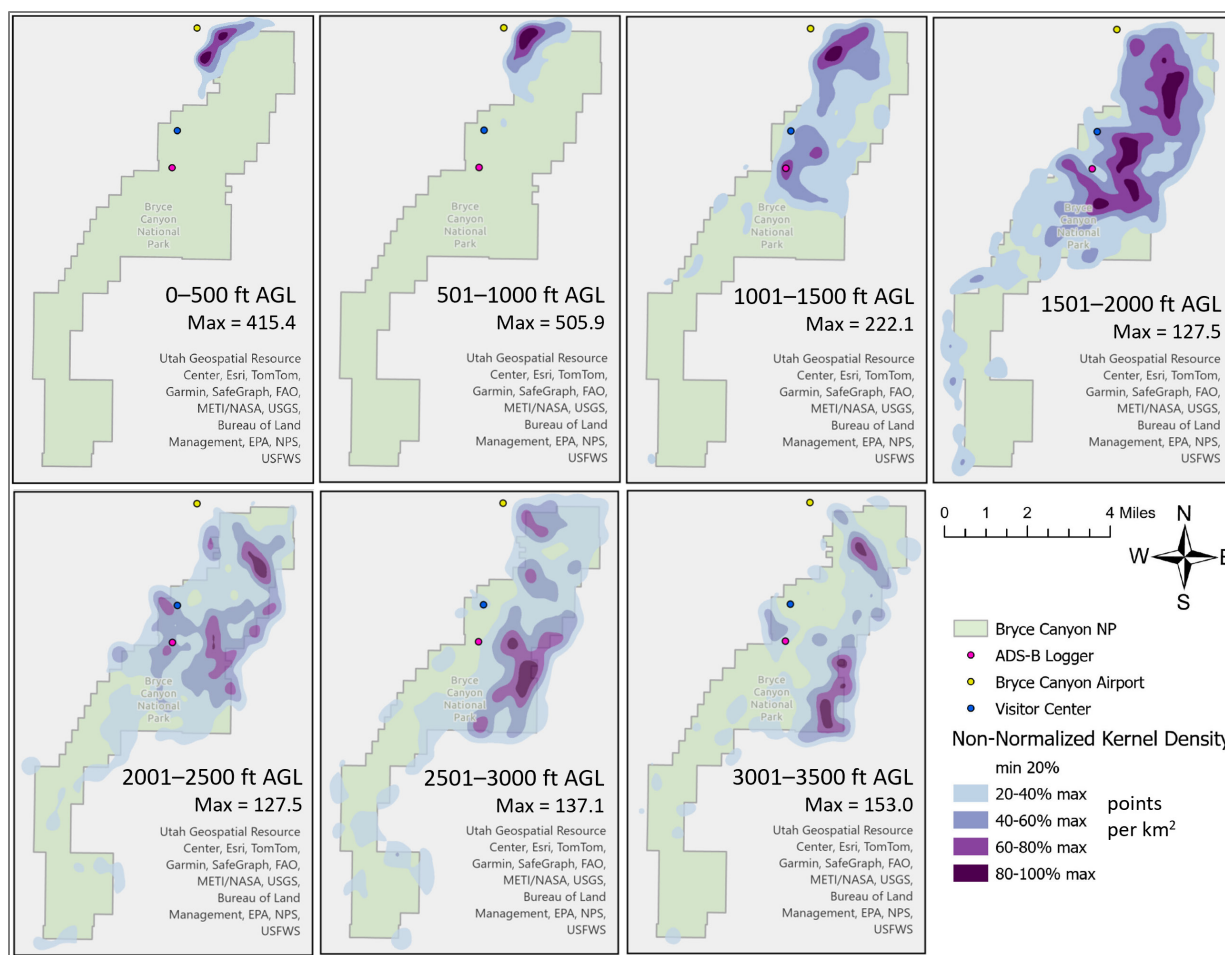


Figure 10. Non-normalized kernel density analysis, 0–3,500 ft AGL.

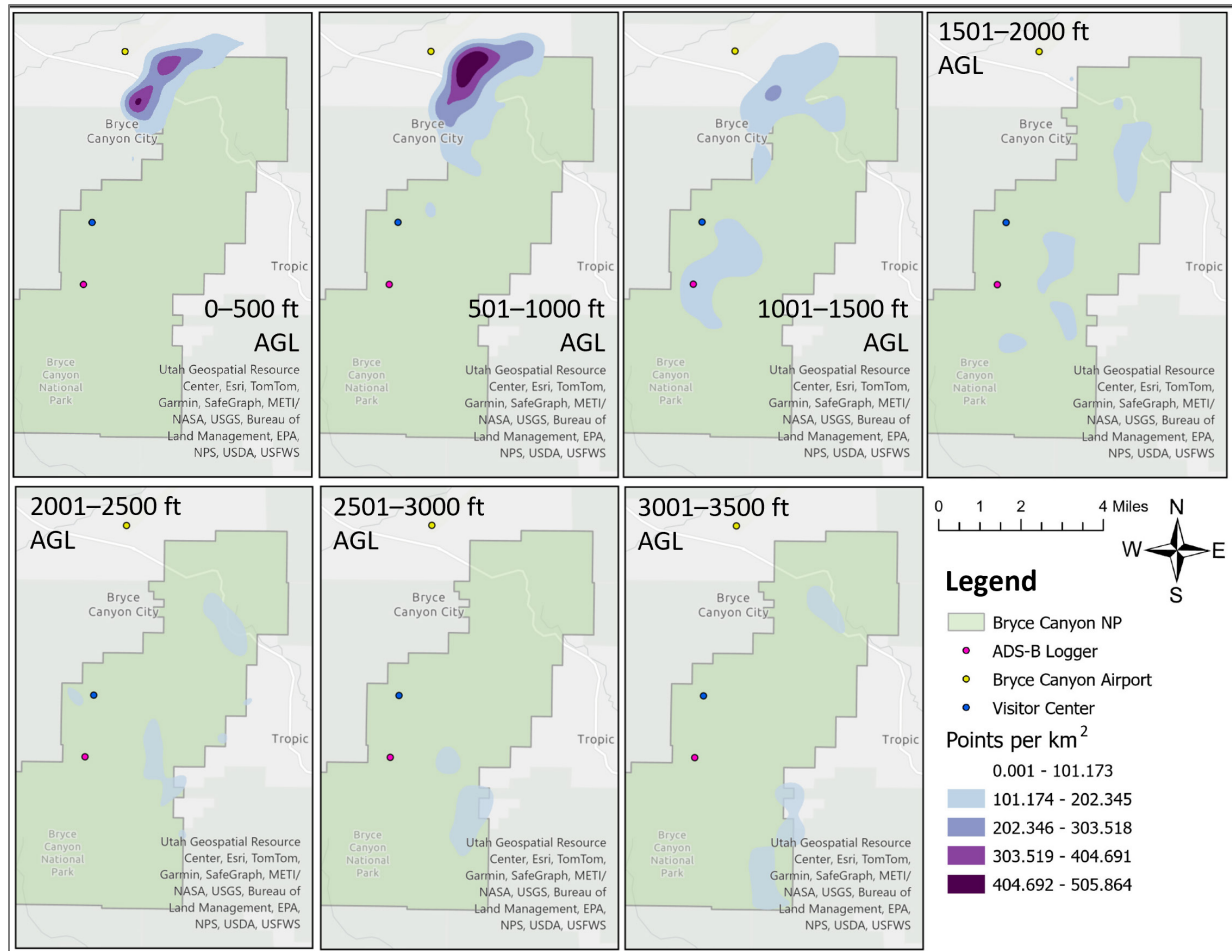


Figure 11. Normalized kernel density analysis, 0–3,500 ft AGL.

The density outputs were statistically compared using a correlation test for the normalized analysis. Altitude intervals that had density hot spots were analyzed (Table 1). The altitude intervals with the highest correlations (correlation coefficient > 0.80) were: 0–500 ft AGL and 501–1,000 ft AGL; and 1,501–2,000 ft AGL and 2,501–3,000 ft AGL. For these altitude intervals, Figure 11 shows similarly shaped density hot spots. This means that across altitude levels, flights are concentrating in similar areas; however, the correlations decrease as altitude increases.

Table 1. Spatial correlation matrix of Above Ground Level (AGL) altitude point densities.

AGL Altitude Interval	1.	2.	3.	4.	5.	6.
1. 0–500 ft AGL	–	–	–	–	–	–
2. 501–1,000 ft AGL	0.93	–	–	–	–	–
3. 1,001–1,500 ft AGL	0.60	0.73	–	–	–	–
4. 1,501–2,000 ft AGL	0.38	0.52	0.84	–	–	–
5. 2,001–2,500 ft AGL	0.31	0.42	0.76	0.88	–	–
6. 2,501–3,000 ft AGL	0.36	0.48	0.71	0.84	0.83	–
7. 3,001–3,500 ft AGL	0.24	0.34	0.61	0.75	0.83	0.83

To further understand altitude trends of waypoints, five visualizations were produced that focus on waypoints within 0.5-mile of the BRCA boundary. Figure 12 examines altitudes less than 0 ft AGL. Any tracking point with a negative AGL is due to error, although it can be challenging to identify the cause of each error. Examination of these data indicate that many of the negative values occur in the northwestern corner of the park—before or after a dramatic topographic change in the landscape, en route to or from the Bryce Canyon Airport—suggesting that a slight error in the barometric pressure. Notably, the total number of negative values is 331 waypoints, out of 64,748 total waypoints, accounting for only 0.5% of the data.

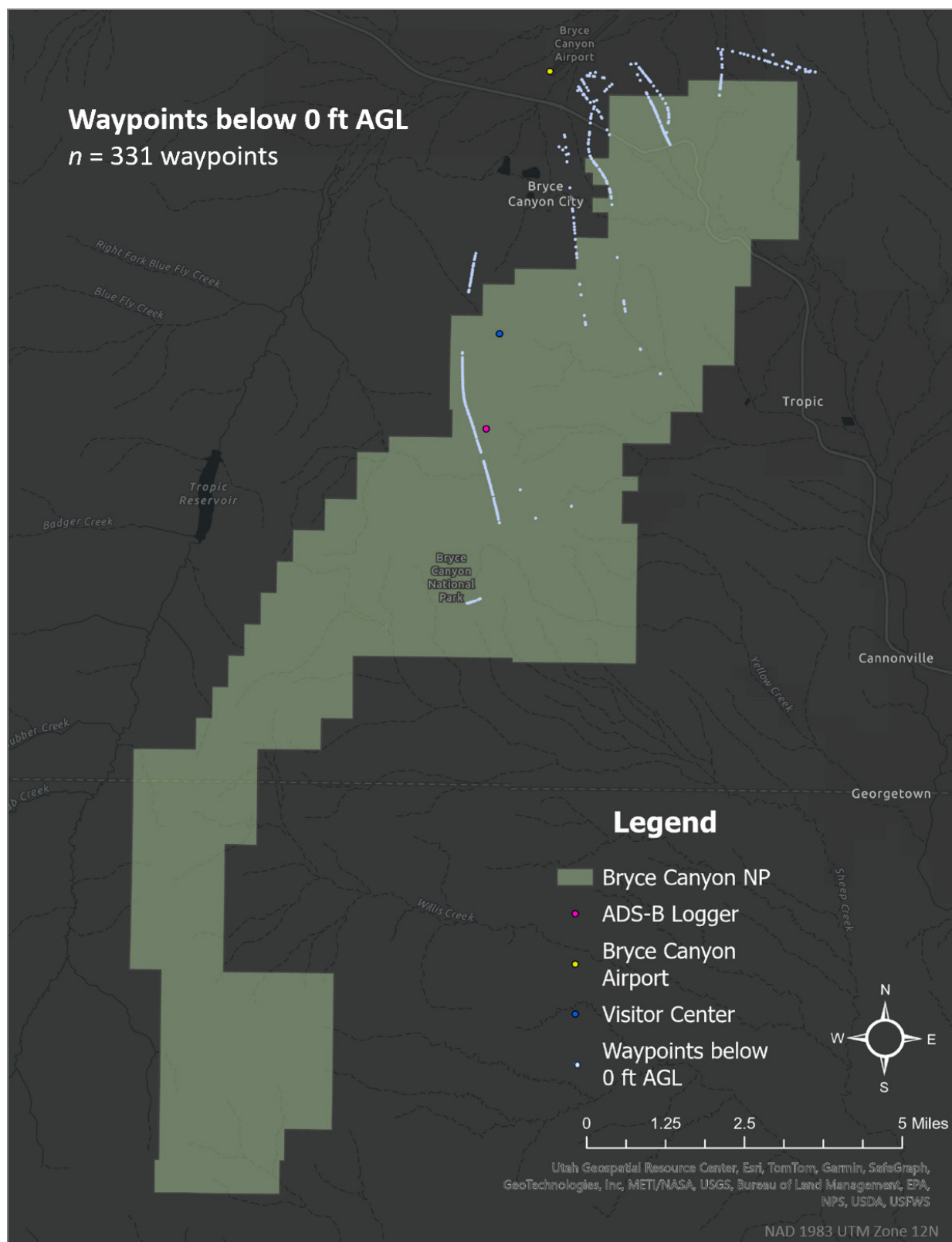


Figure 12. AGL altitude trends of altitudes less than 0 ft AGL for waypoints within 0.5-mile of the BRCA boundary (n=331 waypoints).

Figures 13 (altitudes ranging from 0–2,500 ft AGL) and 14 (altitudes ranging from 2,501–5,000 ft AGL) display AGL altitude trends slightly clustered near the Bryce Canyon Airport and over the main amphitheater. The majority of waypoints are below 3,000 ft AGL.

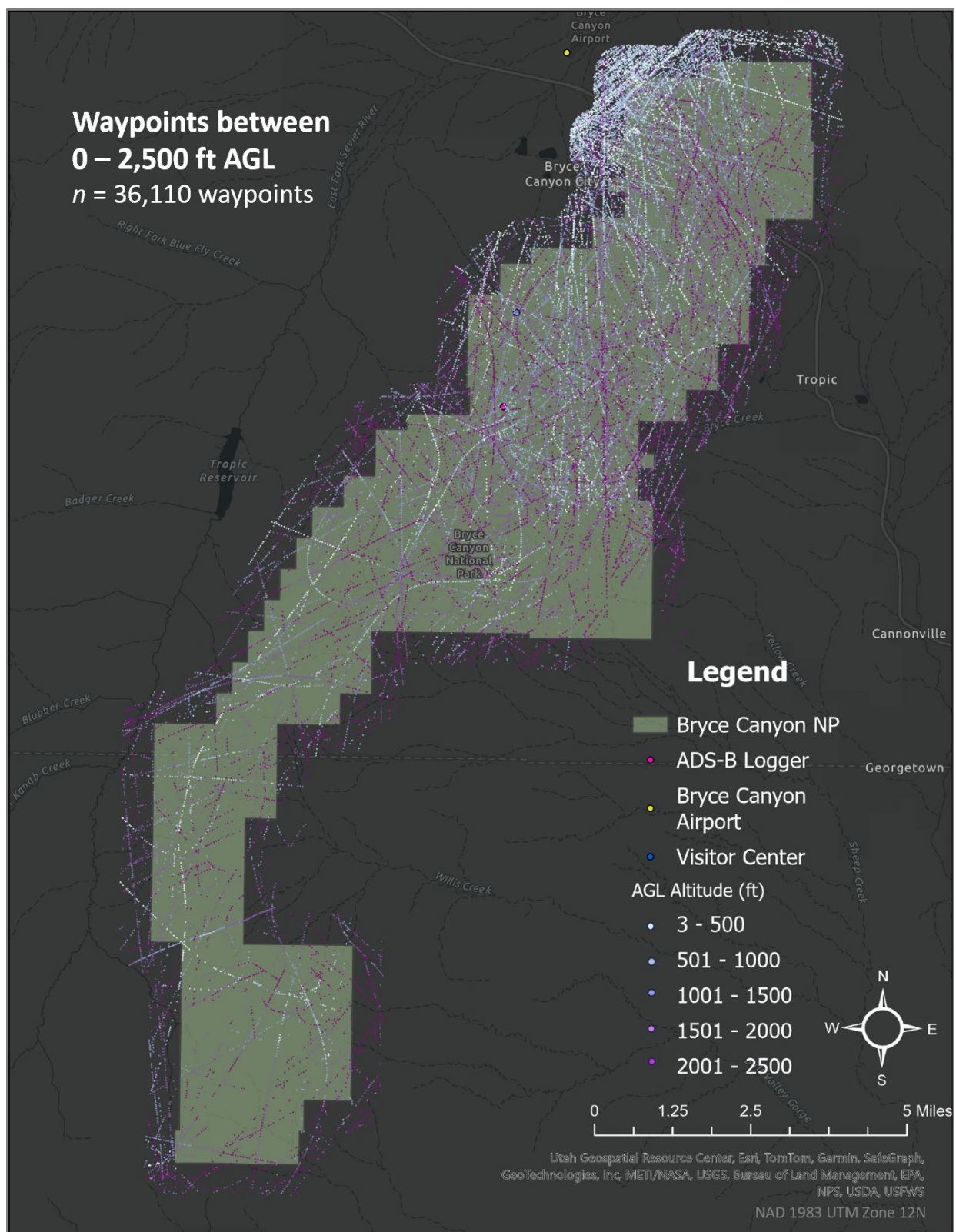


Figure 13. AGL altitude trends of altitudes ranging from 0–2,500ft AGL for waypoints within 0.5-mile of the BRCA boundary ($n = 36,110$ waypoints).

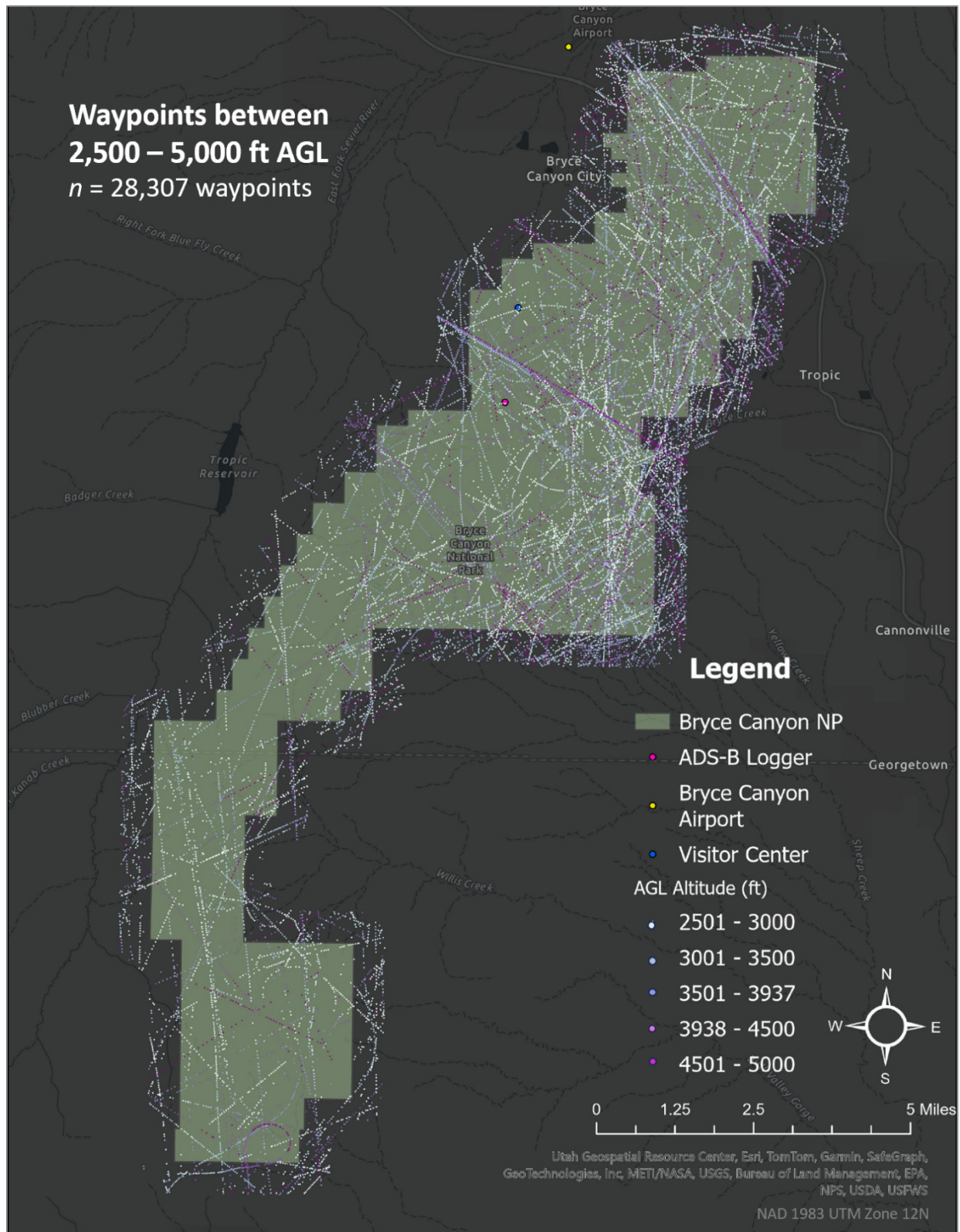


Figure 14. AGL altitude trends of altitudes ranging from 2,501–5,000 ft AGL for waypoints within 0.5-mile of the BRCA boundary (n = 28,307 waypoints).

Figures 15 and 16 display altitude trends expressed in MSL, from the lowest point in the park to about 2,400 feet above the highest point: between 6,620–9,000 ft MSL and between 9,001–11,500 ft MSL.

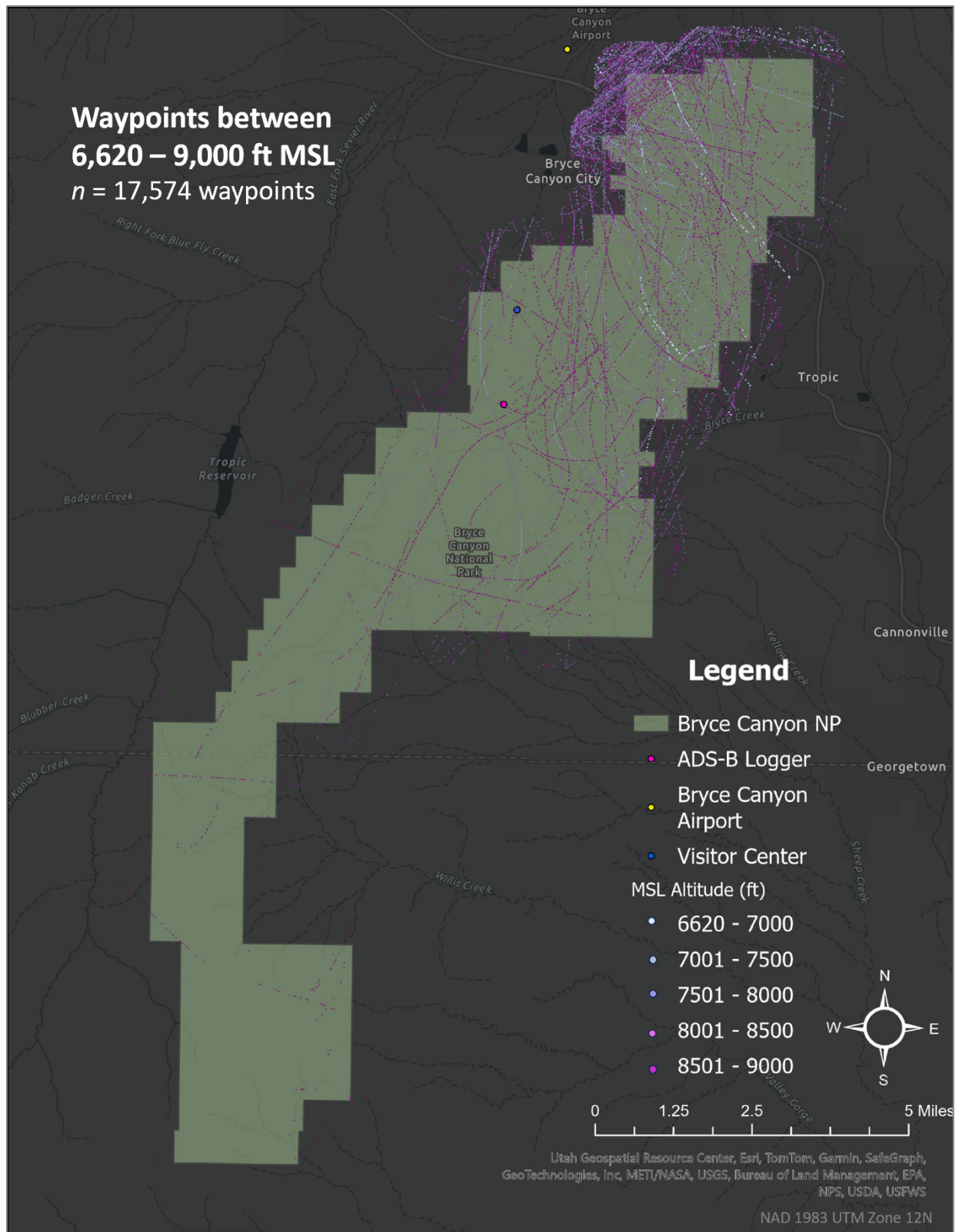


Figure 15. MSL altitude trends of altitudes ranging from 6,620–9,000 ft MSL for waypoints within 0.5-mile of the BRCA boundary ($n = 17,574$ waypoints).

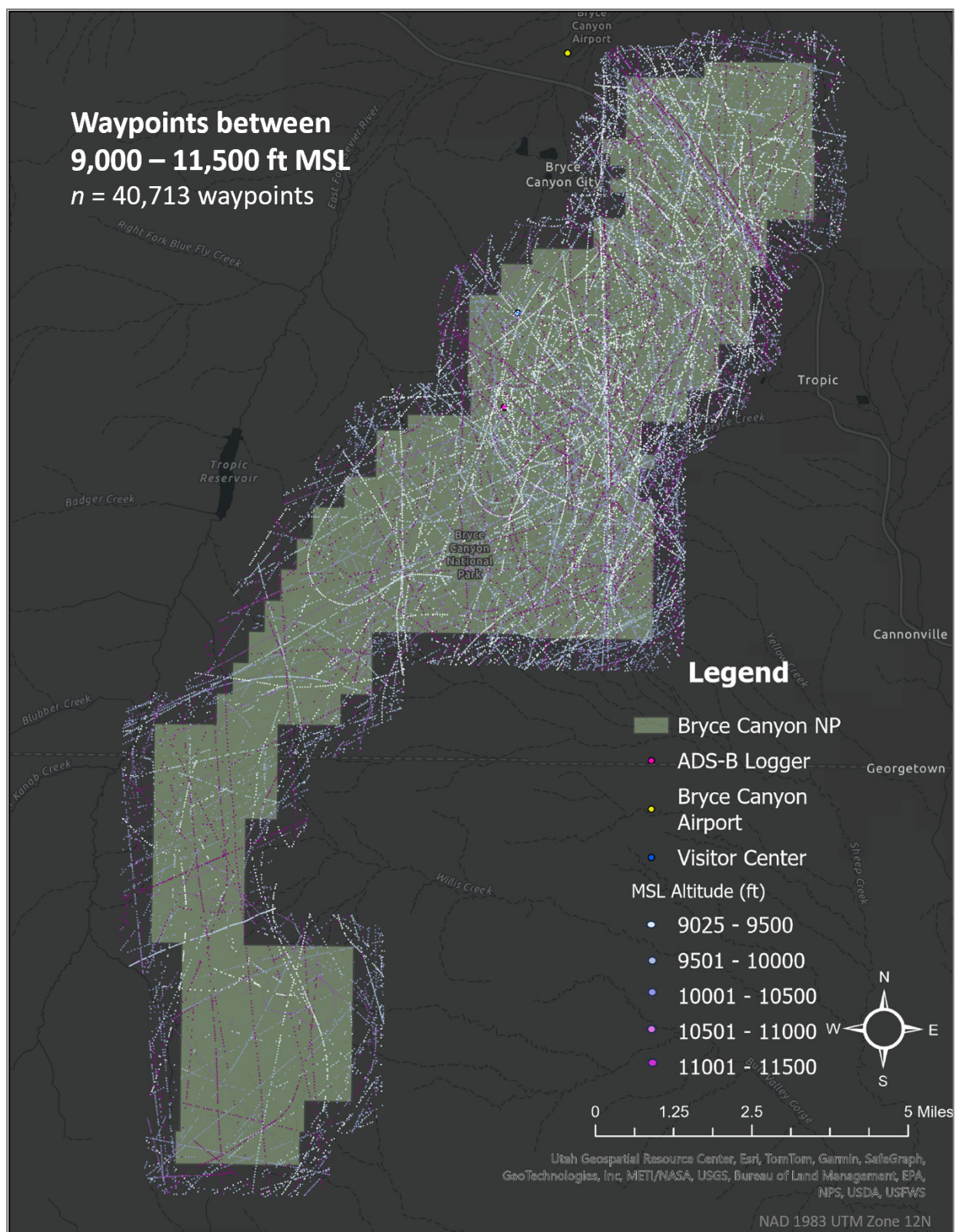


Figure 16. MSL altitude trends of altitudes ranging from 9,001–11,500 ft MSL for waypoints within 0.5-mile of the BRCA boundary ($n = 40,713$ waypoints).

The Phase 3 data for low-level flights displayed in Figures 12–16 were inputted into tables (Tables 2 and 3) to quantitatively understand which altitude intervals had the highest percentage of waypoints. Table 2 shows analysis of 64,748 waypoints across AGL altitudes and Table 3 shows analysis of 64,748 waypoints across MSL altitudes. Altitude intervals between 1,001–3,000 ft AGL had the highest percentage of waypoints. In terms of MSL, the altitude interval between 10,001–10,500 ft had the highest percentage of waypoints, with 9,001–9,500 ft second highest.

Table 2. Number and percentage of waypoints across AGL altitude intervals ($n = 64,748$).

AGL altitude	Number of waypoints	Percentage of waypoints
< 0ft	331	0.5
0–500 ft	3,588	5.5
501–1,000 ft	6,558	10.1
1,001–1,500 ft	8,098	12.5
1,501–2,000 ft	9,150	14.1
2,001–2,500 ft	8,716	13.5
2,501–3,000 ft	8,334	12.9
3,001–3,500 ft	7,025	10.8
3,501–4,000 ft	6,003	9.3
4,001–4,500 ft	4,180	6.5
4,501–5,000ft	2,765	4.3

Table 3. Number and percentage of waypoints across MSL altitude intervals ($n = 64,748$).

MSL altitude	Number of waypoints	Percentage of waypoints
< 6,620 ft	0	0
6,620–7,000 ft	10	0.0
7,001–7,500 ft	297	0.5
7,501–8,000 ft	2,515	3.9
8,001–8,500 ft	7,223	11.2
8,501–9,000 ft	7,529	11.6
9,001–9,500 ft	9,480	14.6
9,501–10,000 ft	6,972	10.8
10,001–10,500 ft	12,659	19.6
10,501–11,000 ft	4,038	6.2
11,001–11,500 ft	7,564	11.7
> 11,501 ft	6,461	10.0

Next, overflights were analyzed across months, days of the week, and hours of the day (total flights analyzed = 2,298.) Table 4 shows the number of days each month that low-level overflight data were collected, overflights per month, and average number of flights per day for the data collection duration, August 14, 2023 to March 12, 2024. The greatest number of overflights took place in October 2023 ($n = 451$) with the highest average number of daily overflights occurring in September 2023 (14.8 flights per day). January saw the least number and lowest average, at 6.3 flights per day for a total of 195 flights.

Table 4. Number and percentage of overflights across months ($n = 2,298$).

Month	Number of data collection days	Number of overflights	Average number of overflights per day (Phase 3 data)
August 2023	18	204	11.3
September 2023	30	444	14.8
October 2023	31	451	14.5
November 2023	30	300	10.0
December 2023	31	285	9.2
January 2024	31	195	6.3
February 2024	29	303	10.4
March 2024	12	116	9.7
Total	573	2298	10.8

Table 5 shows percentage of flights across days of the week. Flights varied little on weekdays as opposed to weekends, with the percentage of flights only slightly higher on Saturdays (17.3%) than on Wednesdays (15.2%), and the lowest percentage of flights on Tuesdays (12.2%).

Table 5. Percentage of overflights across days of the week.

Day of the week	Percent of overflights
Monday	13.1
Tuesday	12.2
Wednesday	15.2
Thursday	13.8
Friday	14.7
Saturday	17.3
Sunday	13.7

Table 6 shows percentage of overflights across hour of the day. Most low-level overflights occur midday, 10 am to 5 pm.

Table 6. Percentage of overflights across hours of the day.

Hour	Percentage of overflights
6:00 am–7:00 am	0.0
7:00 am–8:00 am	0.4
8:00 am–9:00 am	2.3
9:00 am–10:00 am	6.2
10:00 am–11:00 am	8.7
11:00 am–12:00 pm	9.3
12:00 pm–1:00 pm	12.6
1:00 pm–2:00 pm	11.4
2:00 pm–3:00 pm	9.8
3:00 pm–4:00 pm	9.9
4:00 pm–5:00 pm	9.0
5:00 pm–6:00 pm	7.2
6:00 pm–7:00 pm	4.8
7:00 pm–8:00 pm	3.2
8:00 pm–9:00 pm	2

Table 7 shows percentage of overflights by aircraft type. Fixed-wing single engine aircraft are, by far (66%), most common. Together with multi-engine planes, fixed-wing aircraft make up nearly 90% of the low-level air traffic over BRCA. Only 3.2% are rotorcraft.

Note that a significant number and percentage of aircraft (n=160, representing 7%) only transmitted locational ADS-B data, without identifying information such as the N-number, aircraft model, or name of the individual or company to whom the aircraft is registered, resulting in “null” values.

Table 7. Percentage of overflights across aircraft type.

Aircraft type	Percentage
Fixed-wing single engine	66
Fixed-wing multi-engine	23.7
Rotorcraft	3.2
Glider (n = 1)	0
Null / no value (n = 160)	7

Using the cleaned Phase 3 dataset, four more figures were produced to show overflight travel patterns across aircraft type. Figures 17 and 18 display overflight travel patterns for fixed-wing single engine and multi-engine aircraft, respectively. Figure 19 displays overflight travel patterns for

rotorcraft. Because “null” values for unidentified comprise such a large percentage of the flights, their flight patterns are visualized separately in Figure 20.

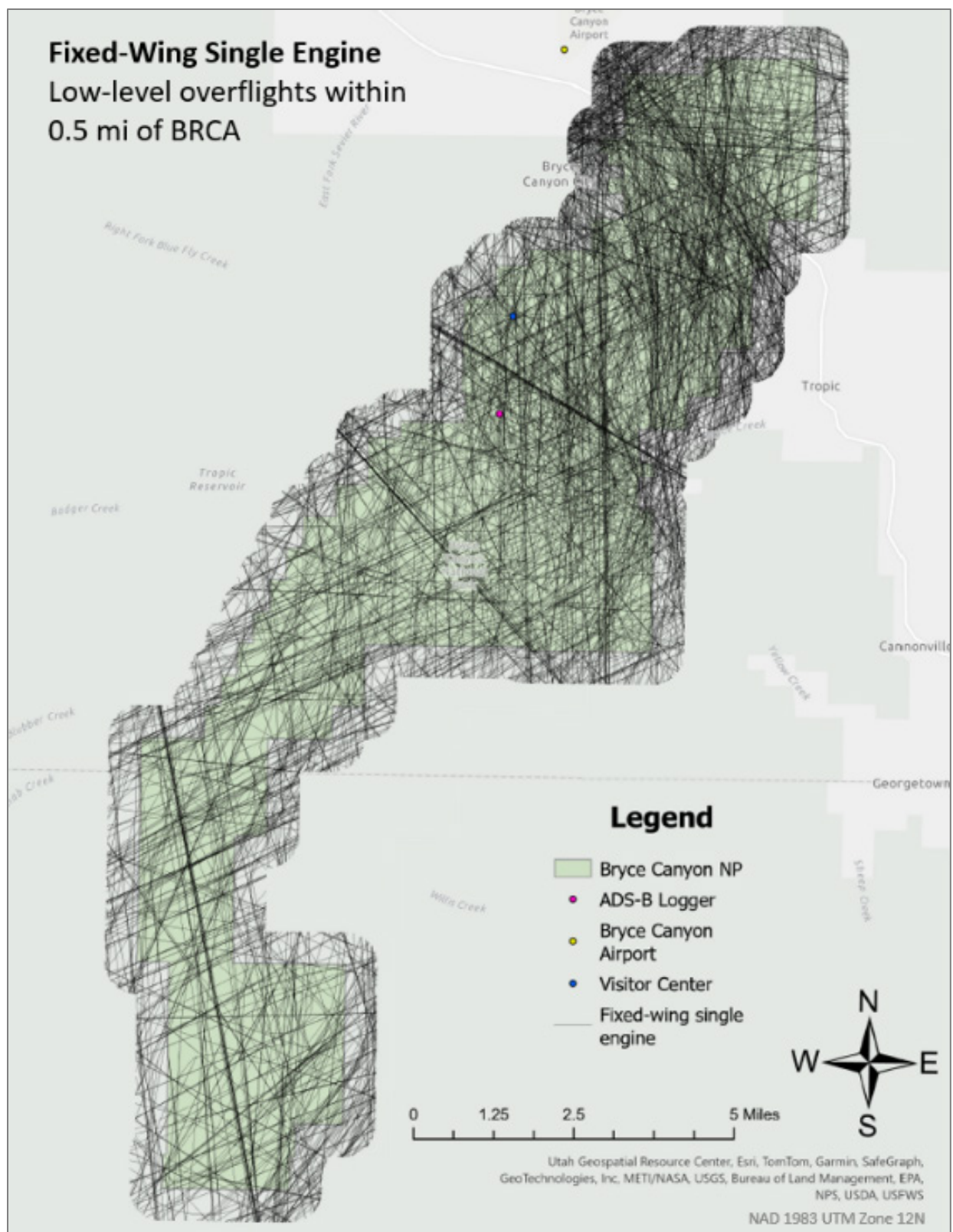


Figure 17. Fixed-wing single engine overflight travel patterns within 0.5 of BRCA.

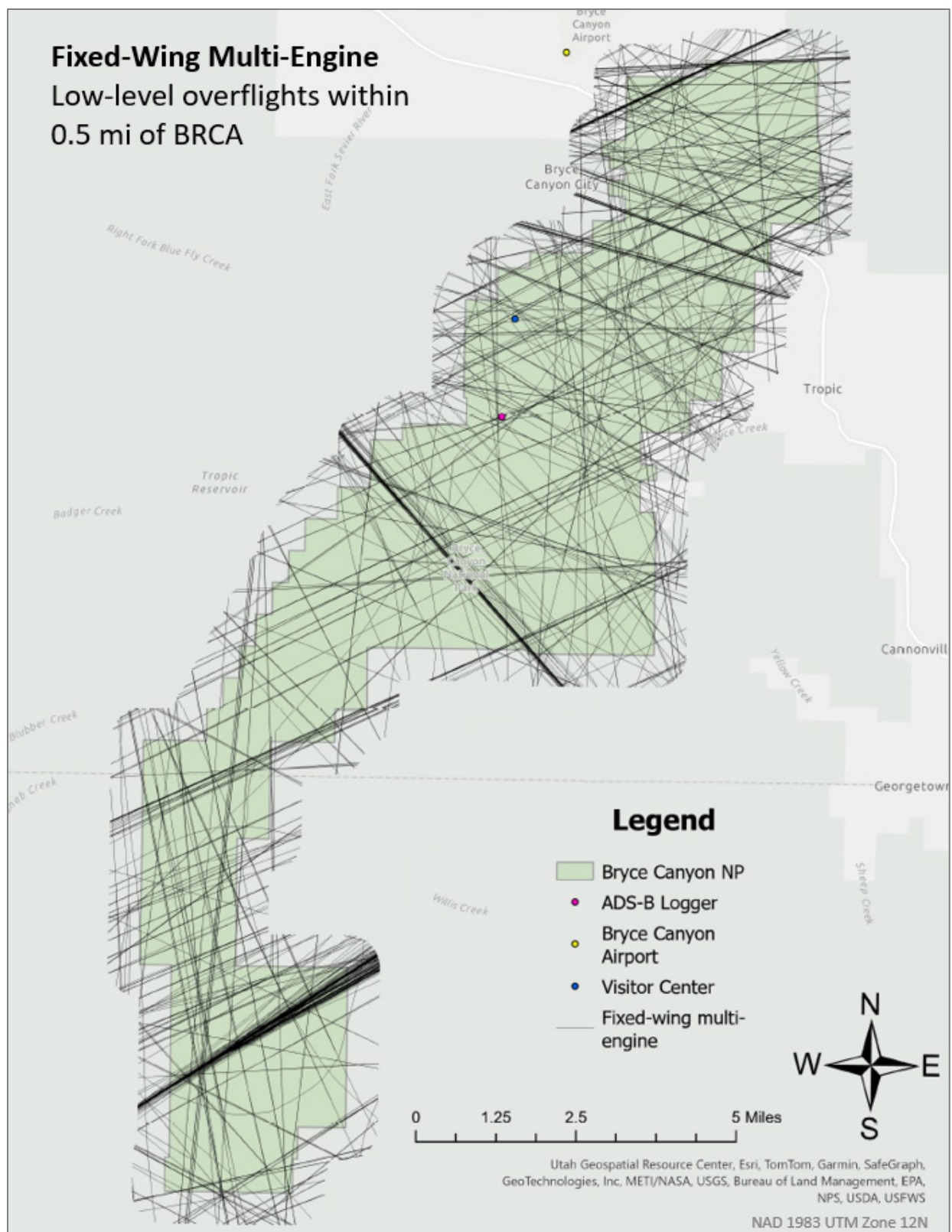


Figure 18. Fixed-wing multi-engine overflight travel patterns within 0.5 mi of BRCA.

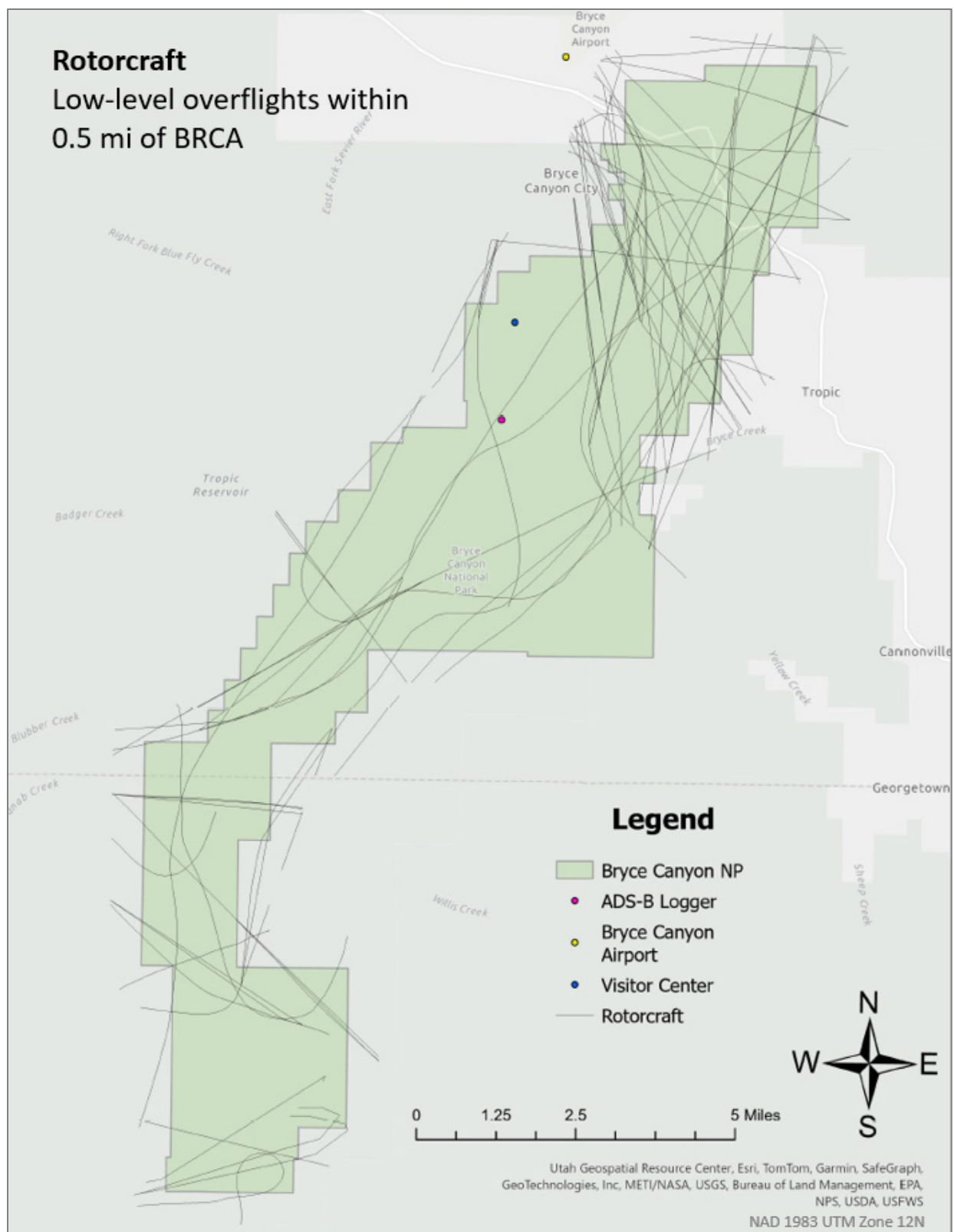


Figure 19. Rotorcraft overflight travel patterns within 0.5 mi of BRCA.

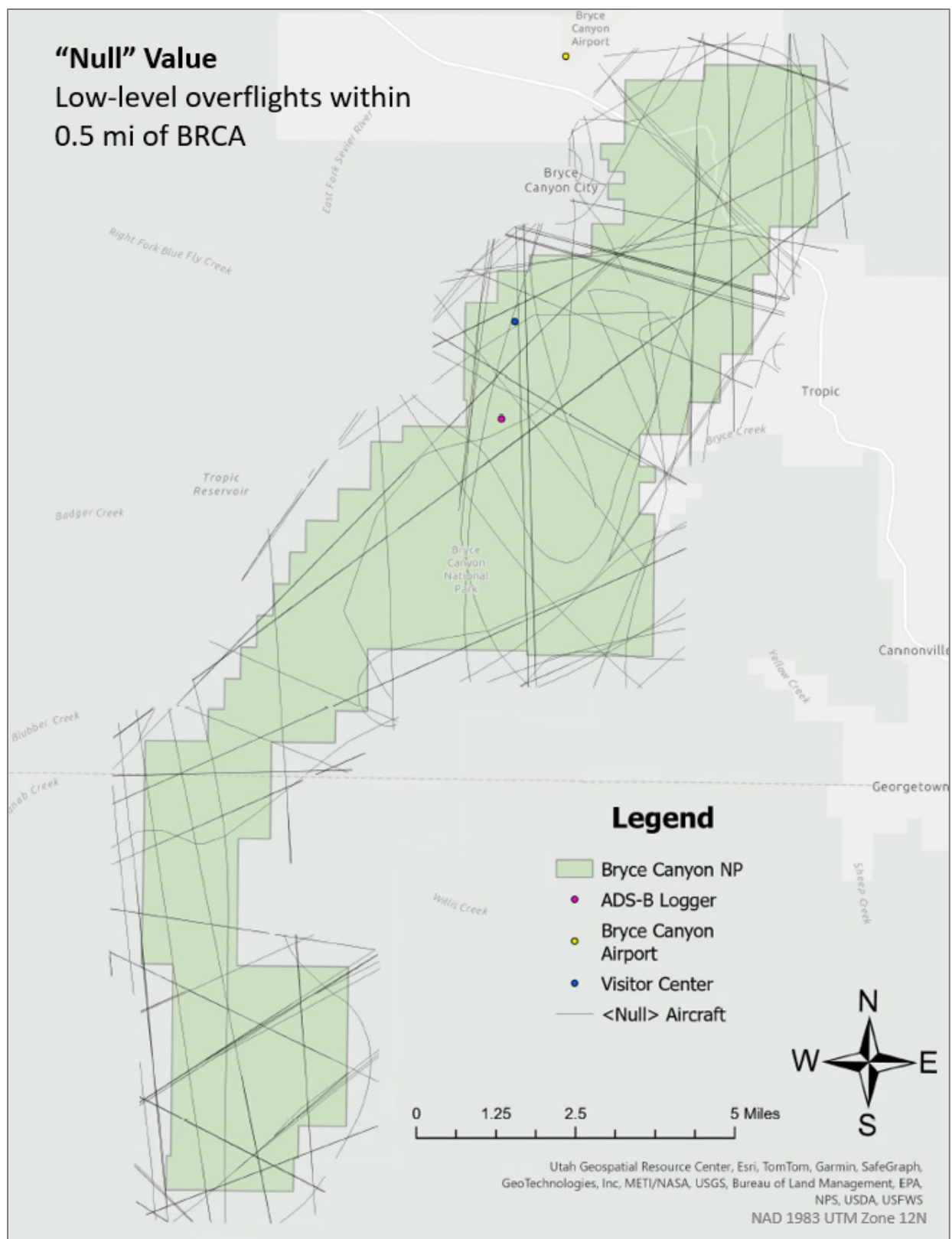


Figure 20. Low-level overflight travel patterns for unidentified or "Null" aircraft within 0.5 mi of BRCA.

Although it is not the intent of this report to evaluate compliance with the park’s Air Tour Management Plan, with this size dataset, it was feasible to separate low-level overflights conducted by permitted commercial air tour operators. Waypoints were selected based on the aircraft type, then investigated by the registrant’s name and/or the N-Number. Although no waypoints are attributable to the operators with the greatest number of allocations as of October 2022—Aero-Copters of Arizona, Inc. and Grand Canyon Airlines, Inc.—both American Aviation, Inc. and Papillon Airways, Inc. flew routes during the period of data collection. Figure 21 displays their flight paths (n=3 and n=8, respectively).

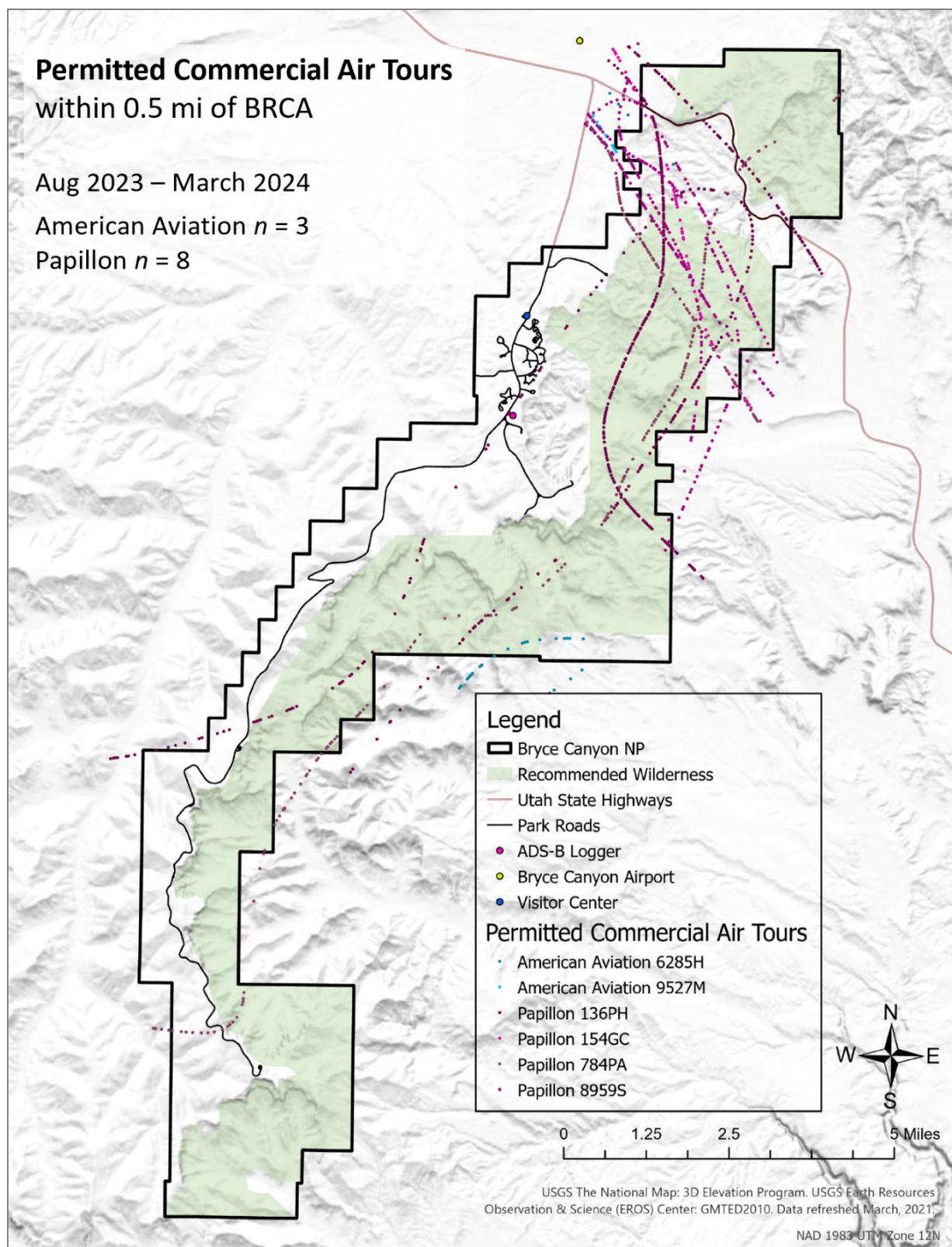


Figure 21. Routes of Permitted Commercial Air Tours.

Discussion

The purpose of this study was to explore the spatial and temporal patterns of overflights at BRCA. Flight tracking data were analyzed from August 14, 2023 to March 12, 2024 (212 total days). An ADS-B logger was deployed near the rim of the main amphitheater, at an exposed location where it was likely to receive most of the data transmitted from airspace over the entirety of the park. There may have been some terrain shielding for any extremely low-altitude flights below the rim in the south end of the park, particularly off Yovimpa Point.

Analysis consisted of three phases. The first phase focused on all overflights within 10 miles, indicating airspace that is dominated by high-altitude transportation flight paths. Although this traffic is not the focus of this report, frequent high-altitude engine noise can still impact the acoustic environment, wildlife, visitors' experiences, and wilderness character within the park. Understanding these traffic patterns is important to understanding the acoustic environment across the park.

The second phase focused on low-level overflights (defined as less than 11,500 ft MSL). Using these data, there's a node of activity around Bryce Canyon Airport below 9,500 ft MSL, but few spatial patterns at higher altitudes or across the park at any altitude.

The third phase aimed to focus more specifically on low-level scenic touring by removing flights known not to be air tours. The dataset was cleaned of 169 civil patrol flights, 1,847 straight-line flights, 3 flights with a flightpath less than a mile in length, 0 survey flights, and 147 commercial airline flights. The remaining flights do not represent solely air tours, however there are management considerations associated with air tours that do not exist for other types of flights. As importantly, any low-level flights that concentrate in particular areas and/or that linger or loop over BRCA for a longer amount of time contribute louder, longer-duration noise to the acoustic environment, having the greatest potential to disturb wildlife and visitors. Geospatial and quantitative analyses of these flights can improve understanding of anthropogenic impacts on the park's acoustic environment.

Fixed-wing single engine aircraft were most commonly detected at low elevations over and within 0.5 mile of the park. Together with multi-engine aircraft, fixed-wing aircraft make up 90% of traffic. Rotorcraft only made up 3% of data. However, a significant portion of waypoints (7%) had no identifying information such as aircraft type or registration attached. As visualized in Figures 17–20, low-level tours are mostly comprised of straight-line flights traversing the park, with only a few flights displaying looping or S-curve flight patterns.

Many analyses in this report evaluate data based on altitude above ground level. Because terrain varies so greatly within the park, this enables greater understanding of the flights' relationship with ground-level phenomena than would altitude above mean sea level alone. Flights at altitudes lower than 1,000 ft AGL, especially lower than 500 ft AGL, cause greater increases in ground-level sound levels than do flights at higher altitudes. Additionally, the FAA recommends pilots fly above 2,000ft AGL over parks, wildlife refuges, and areas with wilderness characteristics; but this is a recommendation, not a regulation (Peterson et al., 2023). Error associated with altitude is a limitation of this analysis. (See the Methods section for more details.)

Figures 10 and 11 display kernel density analysis, revealing that flights are most concentrated toward the Bryce Canyon Airport and the northeast corner of the park, and at an altitude interval of 501–1,000 ft AGL. At higher altitude intervals, flight patterns concentrated over the main amphitheater and Fairyland/Tropic Ditch region up to 3,500 ft AGL, then displayed no spatial patterns. The density of low-level flights in the northern part of the park across multiple altitude bands likely increases disturbances for the terrestrial visitor experience, wildlife, and historic sites. The density (albeit lower level of density) over the amphitheater could represent a number of factors. First, this could mean that more flights are concentrating over this area (regardless of official purpose) because it is scenic or provides an easy navigational aid. This concentration of data could also be because the ADS-B logger is so near, making it easier to capture data over this area.

Table 2 quantifies the number of waypoints within specific AGL altitude bands, showing that the greatest percentage of waypoints occur within the 1,501–2,000 ft AGL interval.

When interpreting the data with respect to position, the latitude and longitude are accurate, but altitude error should be taken into consideration. The data do include negative AGL values—data known for certain to be in error. However, these only represent 0.5% of the data and mostly occur in the vicinity of the Bryce Canyon Airport, suggesting minor error between actual altitude and altitude estimated by barometric pressure. Figure 12 displays the traffic patterns of the <0ft AGL tracks.

Analyses based on MSL values are also useful because pilots use this for in flight decision making and flights do not undulate with the terrain. Table 3 reveals the greatest percentage of overflights occurring in the altitude interval between 10,001–10,500 ft MSL (19.6%), with the second greatest percentage between 9,001–9,500 ft MSL (14.6%). Very few (4.4%) of flights dipped below 8,000 ft MSL (the elevation of Sunset Point), but a substantial percentage were between 8,00–8,500 ft MSL (11.2%) or 8,500–9,000 MSL (11.6%). The park’s Air Tour Management Plan specifies altitudes of 9,250 ft MSL for helicopter routes and 9,750 ft MSL for fixed-wing routes.

Temporal patterns of flights were examined. Table 4 indicates more flights during autumn months (Sept–Oct) than winter, though data have yet to be collected and analyzed for the remainder of March–August. Table 5 shows no patterns across days of the week, with Saturdays and Wednesdays slightly higher than other days. Table 6 explores overflights across hours of the day, revealing midday—especially 12 pm to 2 pm—as the most popular time for low-level flights, despite updrafts and wind. Sunset hours are also busy, though sunrises are remarkably quiet.

Lastly, Figure 21 provides a display of permitted air tour operator data. While the intent of this report was not to focus too specifically on air tours, a cursory examination of this data was conducted. The data in Figure 21 is so sparse that compliance with the parameters set forth in the ATMP could not be analyzed.

In conclusion, this study was intended to further understanding of overflights, including air tours, at BRCA. The resulting information can be used for planning and management purposes, and can also serve as a resource for future monitoring and research.

Literature Cited

- Beeco, J. A. & Joyce, D. 2019. Automated aircraft tracking for park and landscape planning. *Landscape and Urban Planning* 186, 103–111.
- Beeco, J. A., Joyce, D., & Anderson, S. 2020. Evaluating the use of spatiotemporal aircraft data for air tour management planning and compliance. *Journal of Park and Recreation Administration*, 39(1).
- FAA. 2023a. Equip ADS-B. Available at: https://www.faa.gov/air_traffic/technology/equipadsb
- FAA. 2023b. Automatic Dependent Surveillance-Broadcast (ADS-B). Available at: https://www.faa.gov/air_traffic/technology/adsb
- Lignell, B. W. 2020. Reporting information for commercial air tour operations over units of the national park system: 2019 annual report. Fort Collins, Colorado: National Park Service. Natural Resource Report NPS/NRSS/NSNSD/NRR— 2020/2193.
- Peterson, B. A., Brownlee, M. T., Beeco, J. A., Hallo, J. C., White, D. L., & Joyce, D. 2022. Spatiotemporal analysis to understand overflight travel patterns at Hawai‘i Volcanoes National Park. *Journal of Outdoor Recreation and Tourism*, 37, 100476.
- Peterson, B. A., Shively, R. D., Jackson, S. K., Rogowski, J., Beeco, J. A., & Joyce, D. 2023. Using ADS-B Data to Understand Overflight Altitude Characteristics at Hawai‘i Volcanoes National Park. *The Professional Geographer*, 75(1), 118–130.
- United States Geological Survey. 2024. The National Map. Available at: [TNM Download v2 \(nationalmap.gov\)](https://nationalmap.gov)
- United States Geological Survey. 2024. USGS 1/3 Arc Second n38w113 20240227.
- United States Geological Survey. 2021. USGS 1/3 Arc Second n38w112 20211215.
- United States Geological Survey. 2023. Kīlauea. Retrieved from: <https://volcanoes.usgs.gov/volcanoes/kilauea>
- Ward, V. L. and Shields, C. E. 2023. Reporting information for commercial air tour operations over units of the national park system: 2020 annual report. Natural Resource Report NPS/NRSS/NSNSD/NRR—2023/2548. National Park Service, Fort Collins, Colorado. <https://doi.org/10.36967/2299664>

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