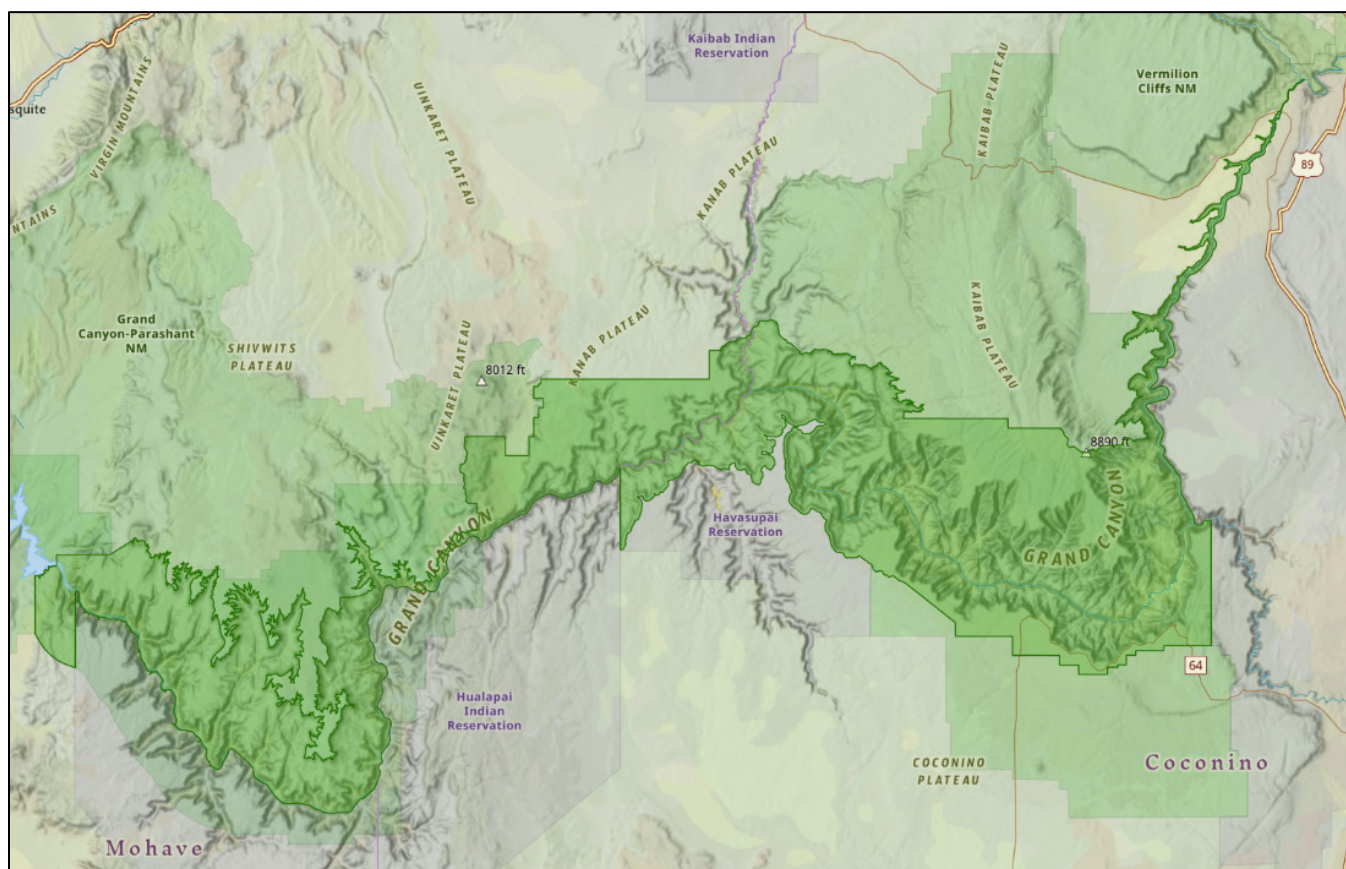




Exploring spatial patterns of overflights at Grand Canyon National Park

Natural Resource Report NPS/GRCA/NRR—2023/2544



ON THE COVER

Map of Grand Canyon National Park.

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Exploring spatial patterns of overflights at Grand Canyon National Park

Natural Resource Report NPS/GRCA/NRR—2023/2544

Brian A. Peterson¹, J. M. Shawn Hutchinson¹, Bijan Gurung¹, J. Adam Beeco², Ashley Pipkin²,
Sharolyn J. Anderson², & Damon Joyce²

¹Kansas State University
Manhattan, Kansas

²National Park Service
Natural Resource Stewardship and Science
Natural Sounds and Night Skies Division
Fort Collins, Colorado

July 2023

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Peterson, B. A., Hutchinson, J. M. S., Gurung, B., Beeco, J. A., Anderson, S. J., & Joyce, D. 2023. Exploring spatial patterns of overflights at Grand Canyon National Park. Natural Resource Report NPS/GRCA/NRR—2023/2544. National Park Service, Fort Collins, Colorado.
<https://doi.org/10.36967/2299660>

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Acknowledgements

The authors would like to thank the National Park Service Natural Sounds and Night Skies Division for funding and supporting this project, and specifically Vicki Ward and Warren Deeds. The authors would also like to thank Michael Kearsley, Claire Morris, Garrison Loope, Cam Prophet and Sarah Haas from Grand Canyon National Park for their tireless support of maintaining the collection units and downloading the data.

Abstract

This study explored spatial patterns of overflights at Grand Canyon National Park (GRCA). Overflights were analyzed from February 5th, 2020 to January 9th, 2023 (975 days of data; 95 days of missing data) using Automatic Dependent Surveillance-Broadcast (ADS-B) data. The first phase of analysis focused on all overflights and found a high concentration of overflights above GRCA and definitive travel patterns across the park. The second phase of analysis focused on low-level overflights that fly below 10,000 ft mean sea level (MSL) and fly within 10-miles of the GRCA boundary. Phase 2 figures display yearly overflights segmented by aircraft type and show a concentration of flights between 7,000 – 10,000 ft MSL near the southeast boundary of GRCA. The third phase of analysis removed all overflights known to not be air tours. Kernel density analysis was conducted using waypoints segmented into 500 ft above ground level (AGL) altitude intervals. The altitude interval with the highest density of overflights was ‘3,001 – 3,500 ft AGL’. This information can be used for planning and management purposes and this study serves as a resource for future research that intends to use more advanced analytics.

List of Acronyms

AGL: Above ground level

ADS-B: Automatic Dependent Surveillance-Broadcast

DEM: Digital Elevation Model

FAA: Federal Aviation Administration

GIS: Geographic Information Systems

GRCA: Grand Canyon National Park

MSL: Mean sea level

NPS: National Park Service

Introduction

Grand Canyon National Park (GRCA) was established in 1919 and is designated as a United Nations Educational, Scientific, and Cultural Organization (UNESCO) World Heritage Site (UNESCO, 2023). GRCA located in northern Arizona, is comprised of 278 miles of the Colorado River Corridor and adjacent lands, and encompasses 1,904 square miles (National Park Service, 2023). The canyon corridor averages 4,000 ft deep, is 6,000 ft at its deepest point, and 18 miles wide at its widest point (National Park Service, 2023). Elevations range from 2,400 ft at Phantom Ranch (National Park Service, 2023) to 8,803 ft on top of Point Imperial (National Park Service, 2022).

Grand Canyon National Park has been an air tour destination for over 100 years. It received its first air tour in 1919 and is now considered the busiest airspace for air tours over any National Park Service (NPS) unit (Rapoza et al., 2022), which has resulted in noise impacts caused by low-level overflights. Consequently, legislation has been passed to restore natural quiet at GRCA. The Moving Ahead for Progress in the 21st Century Act of 2012 (MAP-21, Public Law 112-141) requires all commercial air tour aircraft operating within the Grand Canyon National Park Special Flight Rules Area (SFRA) convert to quiet aircraft technology (QT) by 2027 (Rapoza et al., 2022). The SFRA was established in 1987 and includes GRCA and portions of surrounding lands. It extends vertically to 17,999 ft above mean sea level (MSL) and includes several flight-free zones with maximum altitudes of 14,500 ft MSL on the east and 8,000 ft MSL on the west (National Park Service, 2007). Furthermore, this area is significant because special operational rules and restrictions apply, including: fixed routes and altitudes for air tours, flight-free zones and reporting requirements, and air tour curfews along the east end of the park (National Park Service, 2007) (Figure 1). A detailed chronology of significant events pertaining to Grand Canyon overflights can be found on the NPS Grand Canyon website (https://www.nps.gov/grca/learn/nature/airoverflights_chrono.html).

At GRCA, air tour aircraft with QT technology flown in the first quarter of the year are not subject to flight allocations provided that air tour aircraft noise does not increase (Rapoza et al., 2022) above the 2012 baseline level. To understand if noise impacts have increased, the NPS and Federal Aviation Administration (FAA) analyze each year's commercial air tours' noise impacts within two corridors (Dragon and Zuni Point corridors) and compare it to a 2012 baseline (Rapoza et al., 2022).

The purpose of this report is to provide examination of the spatial patterns of all overflights at GRCA, which may assist in the management and communication between air tour operators, other airspace users, and the park.

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, 2020). However, at GRCA, no airspace requires ADS-B technology. Regardless of the airspace designation, prior studies suggest a rather ubiquitous adoption of ADS-B by aircrafts in the United States. GRCA air tour operators are known to be equipped and operate with ADS-B technology.

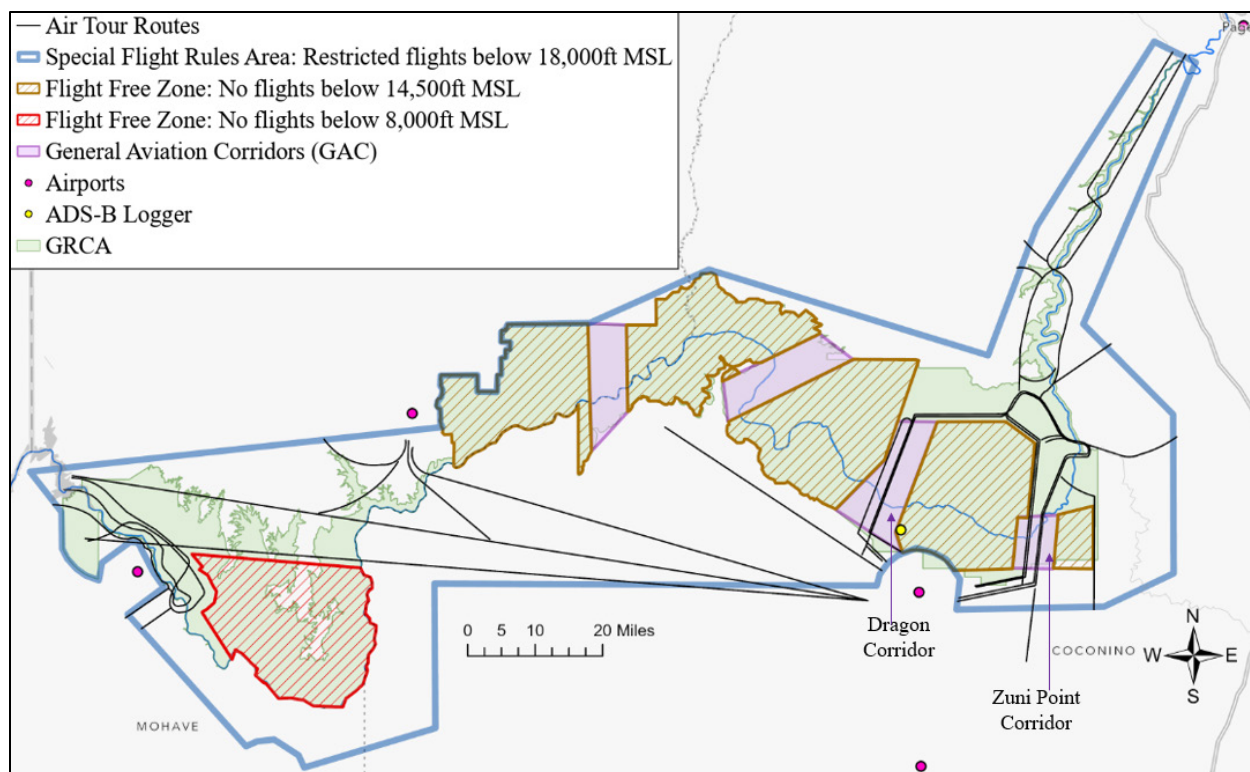


Figure 1. Map of Special Flight Rules area and designated air tour routes.

ADS-B signals are transmitted from aircraft and provide location information and unique identifiers to improve airspace safety and air traffic efficiency (FAA, 2018). This study analyzed overflights using ADS-B technology that flew above GRCA. The data discussed in this report span from February 5th, 2020 to January 9th, 2023 and include 975 days of data and 95 days of missing data. After the data were screened of flights known not to be air tours, the dataset was comprised of 35,279 flights.

Methods

Data Collection

Data were collected by one ADS-B terrestrial data logger, which was located on top of an air quality station tower at The Abyss on the South Rim (36.0586, -112.1836; 6,862 ft elevation) (Figure 2). The data logger was positioned with an unimpeded and expansive skyward exposure. 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 both 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 to not 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 10-meter digital elevation model (DEM) was used (United States Geological Survey, 2021). 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).

To explore spatial patterns of overflights at GRCA, analysis was conducted in three phases. Phase 1 and Phase 2 report altitudes using MSL, while Phase 3 uses AGL. 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 undulate over the terrain and associated terrestrial resources and visitors' experiences. All maps produced during analysis used Esri basemaps with service layer credits for: Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, BLM, EPA, NPS, Esri, CGIAR, and USGS; 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 GRCA regardless of flight type or altitude. Thus, the flightline feature class was not cleaned of any flight types nor was an altitude threshold implemented. To understand how flightpaths extended beyond the park boundary, a 10-mile buffer around the GRCA boundary was used. Three maps were produced. The first map shows overflights from February 5th, 2020 to December 31st, 2020 (all data collected for 2020). The

second map shows overflights from January 1st, 2021 to December 31st, 2021 (all data collected for 2021). The third map shows overflights from January 1st, 2022 to January 9th, 2023 (all data collected for 2022 and nine days of 2023).

Phase 2 methods

The purpose of the second phase was to understand low-level overflights above GRCA 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 10,000 ft MSL. This altitude was chosen because the highest point at GRCA is 8,803ft on top of Point Imperial (National Park Service, 2022), and approximately 1,200 ft above the highest point in the park would capture flights that had the greatest impact on the acoustic environment in the park. To understand flight altitudes, a waypoint feature class was used. Nine maps were produced which show yearly low-level overflights segmented across aircraft type (rotorcraft, fixed wing single engine, fixed wing multi engine).

Phase 3 methods

The purpose of the third phase was to focus on flights that were likely 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 info along with ADS-B data, the toolbox screened for suspected flights known to not be air tours by: 1) cleaning the data of 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. 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 0.80 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 flights were clearly identifiable by their flight patterns. Removal of survey flights was the last cleaning procedure because this step requires visual analysis which is easier to conduct after the other cleaning procedures have been accomplished. 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 without cross checking with every operator or plane owner, a definitive confirmation that all remaining flights are air tours is not possible.

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 impact on GRCA's acoustic environment. Using a 500 ft AGL altitude interval, waypoint data were segmented (0-500 ft AGL; 501-1,000 ft AGL; 1,001-1,500 ft AGL; 1,501-2,000 ft AGL; 2,001-2,500 ft AGL; 2,501-3,000 ft AGL; 3,001-3,500 ft AGL; 3,501-4,000 ft AGL; 4,001-4,500 ft AGL; 4,501-5,000 ft AGL) and kernel density analysis was conducted for each altitude interval. Because each altitude interval had different density results, density classifications were normalized across altitude intervals. To do this, the altitude interval with the highest maximum density of waypoints (3,001-3,500 ft AGL) was used to normalize density classification, which required two steps. First, the 3,001-3,500 ft AGL altitude density was classified using equal interval percentage breaks with five intervals of 20%. These percentage breaks were determined using the maximum density per square kilometer as the '100%' value. Second, the maximum density was segmented across five 20% equal interval classifications. The resulting density classifications were then applied to the other altitude intervals. These steps are necessary to ensure density was calculated the same across altitude intervals regardless of the number of waypoints.

Kernel density analysis revealed dense low-level overflights up to 4,000 ft AGL. Dense low-level overflights were not found for the following two altitude intervals: 4,001 – 4,500 ft AGL and 4,501 – 5,000 ft AGL. This analysis produced three figures. The first figure shows all altitude interval densities merged together (up to 4,000 ft AGL) to serve as a reference for where dense overflights occurred above GRCA. The second figure shows density analysis across sequential intervals ranging from 0 – 2,000 ft AGL. The third figure shows density analysis across sequential intervals ranging from 2,001 – 4,000 ft AGL. After these steps were accomplished, kernel density outputs were statistically compared for relatedness using the 'Band Collection Statistics' tool which conducted a correlation test.

Next, four more figures were produced to spatially compare AGL and MSL waypoint trends. The first figure displays waypoint altitudes between 0 - 2,500 ft AGL using a 500 ft AGL interval. The second figure displays waypoint altitudes between 2,501 - 5,000 ft AGL using a 500 ft AGL interval. Because the South Rim of GRCA is approximately 7,000 ft MSL (National Park Service, 2023), that elevation was used to design the next two figures. The third figure displays waypoint altitudes between 0 - 7,000 ft MSL and the fourth figure displays waypoint altitudes between 7,001 - 10,000 ft MSL.

Next, descriptive analyses were conducted to understand waypoint frequencies across AGL and MSL altitudes; number of flights across months, day of the week, and hour of the day; and number of flights across aircraft types. To gain insight into overflight travel patterns across aircraft types, three more figures were produced for fixed-wing single engine aircraft, fixed-wing multi engine aircraft, and rotorcraft aircraft. Lastly, three figures were produced that display flight routes of operators who conducted the most flights.

Results

Results – Phase 1

Data were collected by a data logger located on top of an air quality station tower at The Abyss on the South Rim (Figure 2). The research team mapped overflights for all flights ($n=272,368$). Figure 3 shows overflights from February 5th, 2020 to December 31st, 2020. Figure 4 shows overflights from January 1st, 2021 to December 31st, 2021. Figure 5 shows overflights from January 1st, 2022 to January 9th, 2023.

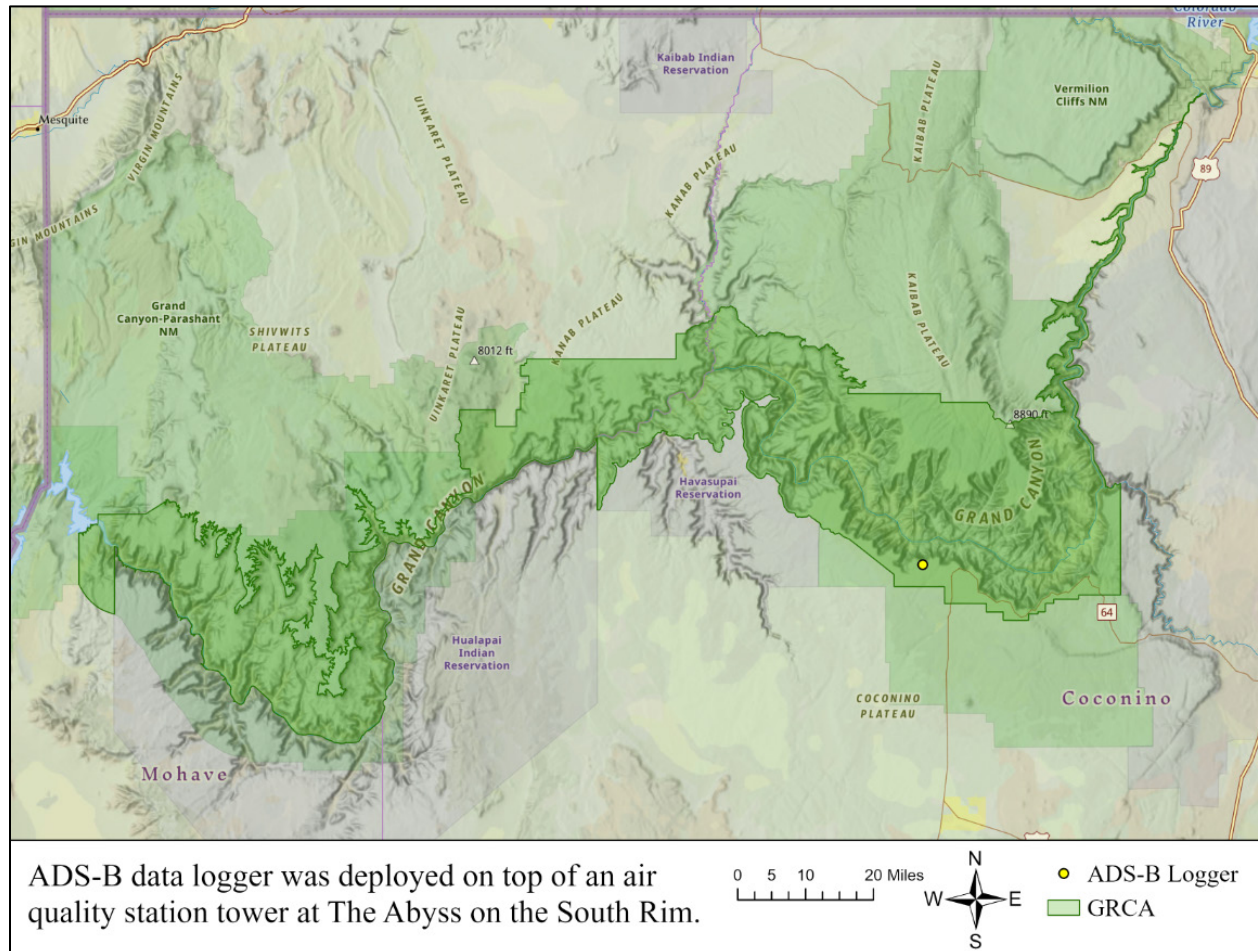


Figure 2. Location of ADS-B data logger.

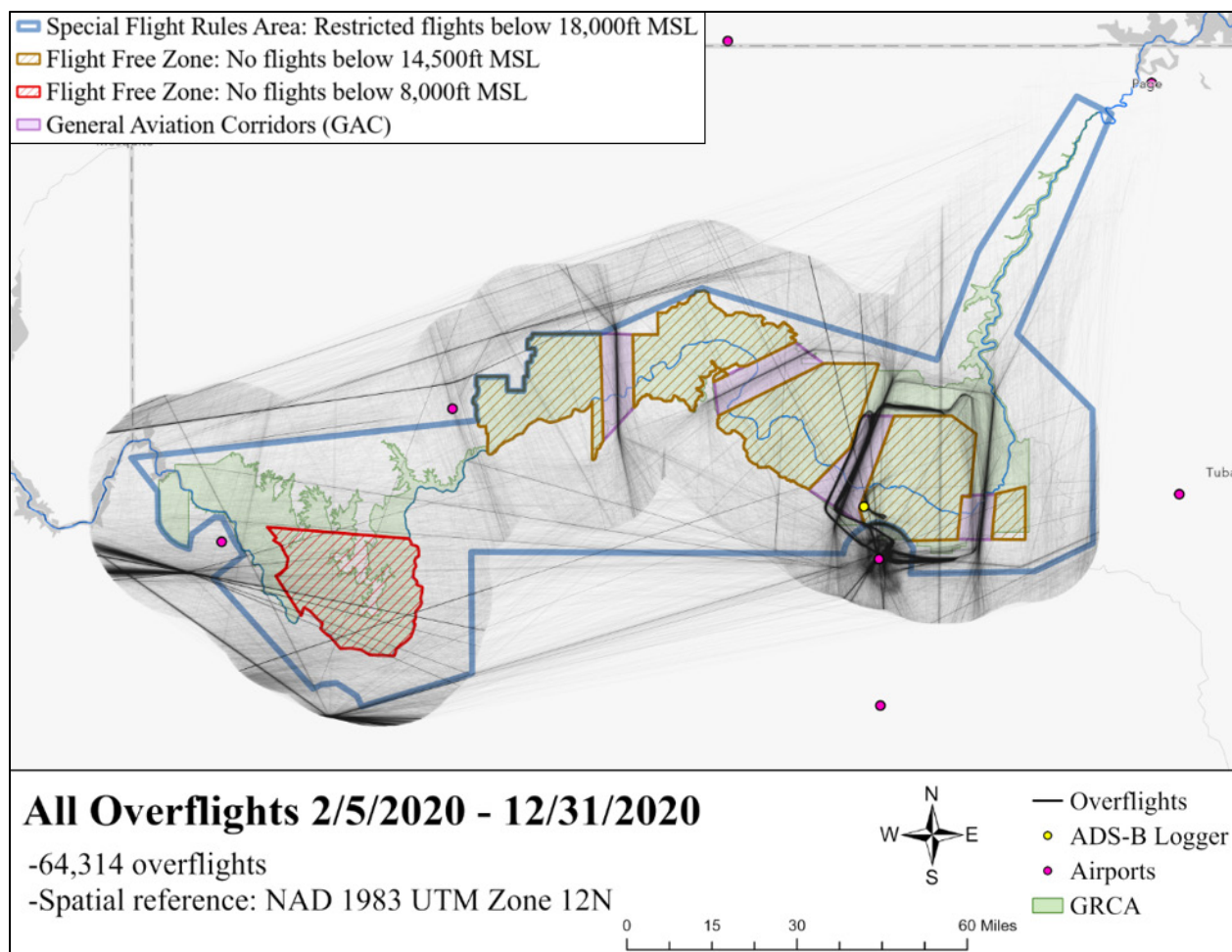


Figure 3. Overflights between February 5th, 2020 to December 31st, 2020.

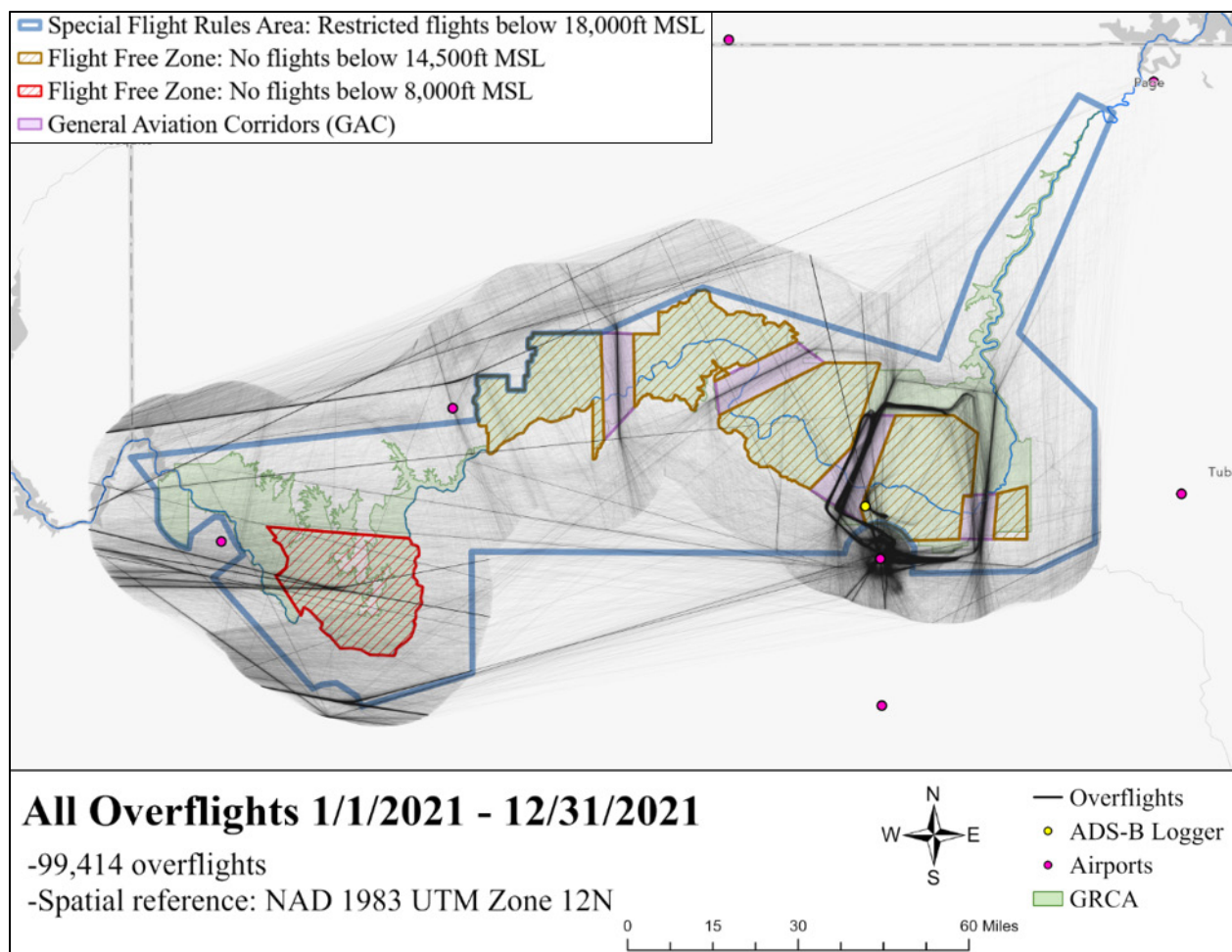


Figure 4. Overflights between January 1st, 2021 to December 31st, 2021.

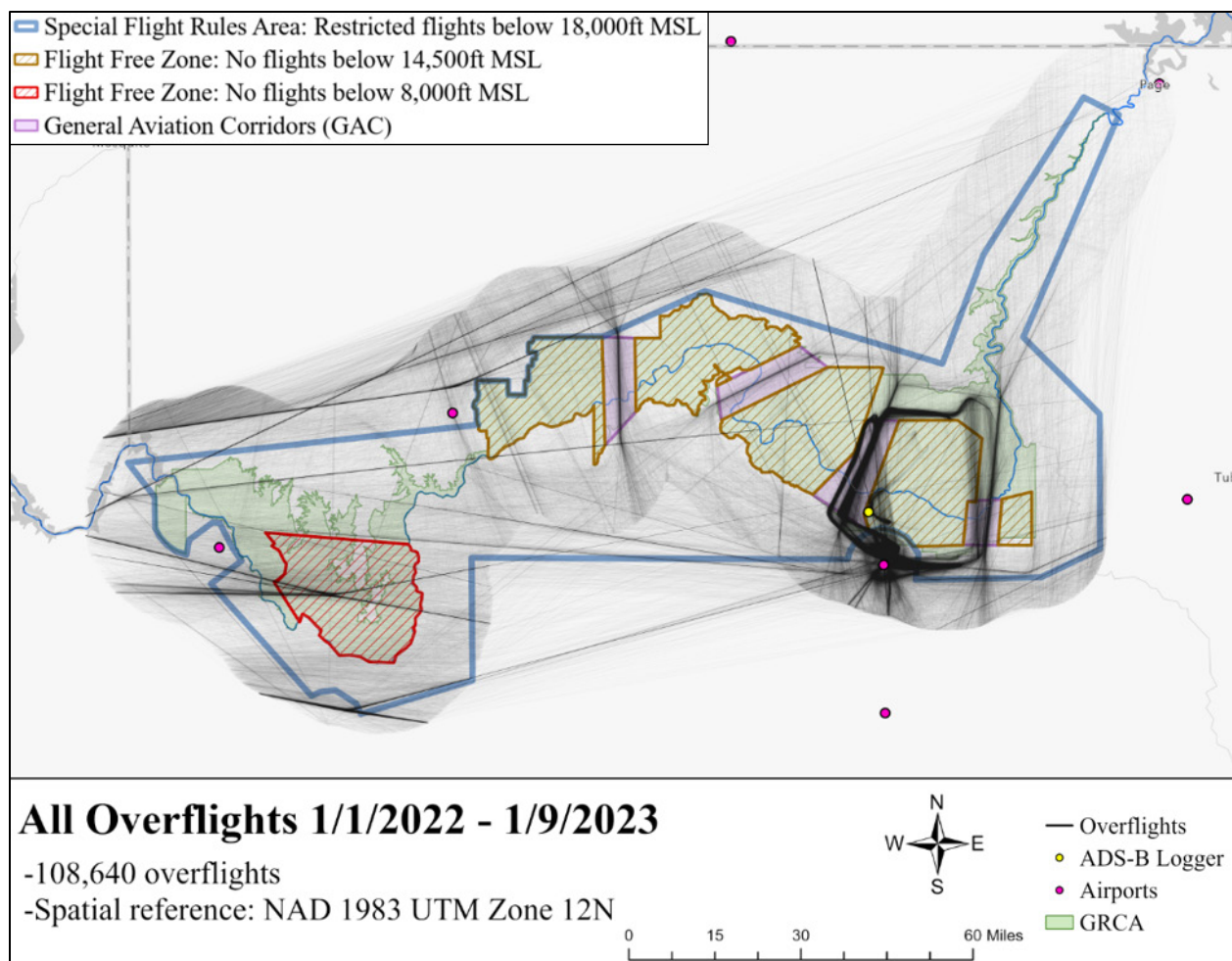


Figure 5. Overflights between January 1st, 2022 to January 9th, 2023.

Results – Phase 2

The research team mapped yearly low-level overflights that flew below 10,000 ft MSL across aircraft types (rotorcraft, fixed wing single engine, fixed wing multi engine). Nine figures were produced. Figures 6 (rotorcraft), 7 (fixed wing single engine), and 8 (fixed wing multi engine) show waypoint MSL altitudes for February 5th, 2020 to December 31st, 2020. Figures 9 (rotorcraft), 10 (fixed wing single engine), and 11 (fixed wing multi engine) show waypoint MSL altitudes for January 1st, 2021 to December 31st, 2021. Figures 12 (rotorcraft), 13 (fixed wing single engine), and 14 (fixed wing multi engine) show waypoint MSL altitudes for January 1st, 2022 to January 9th, 2023.

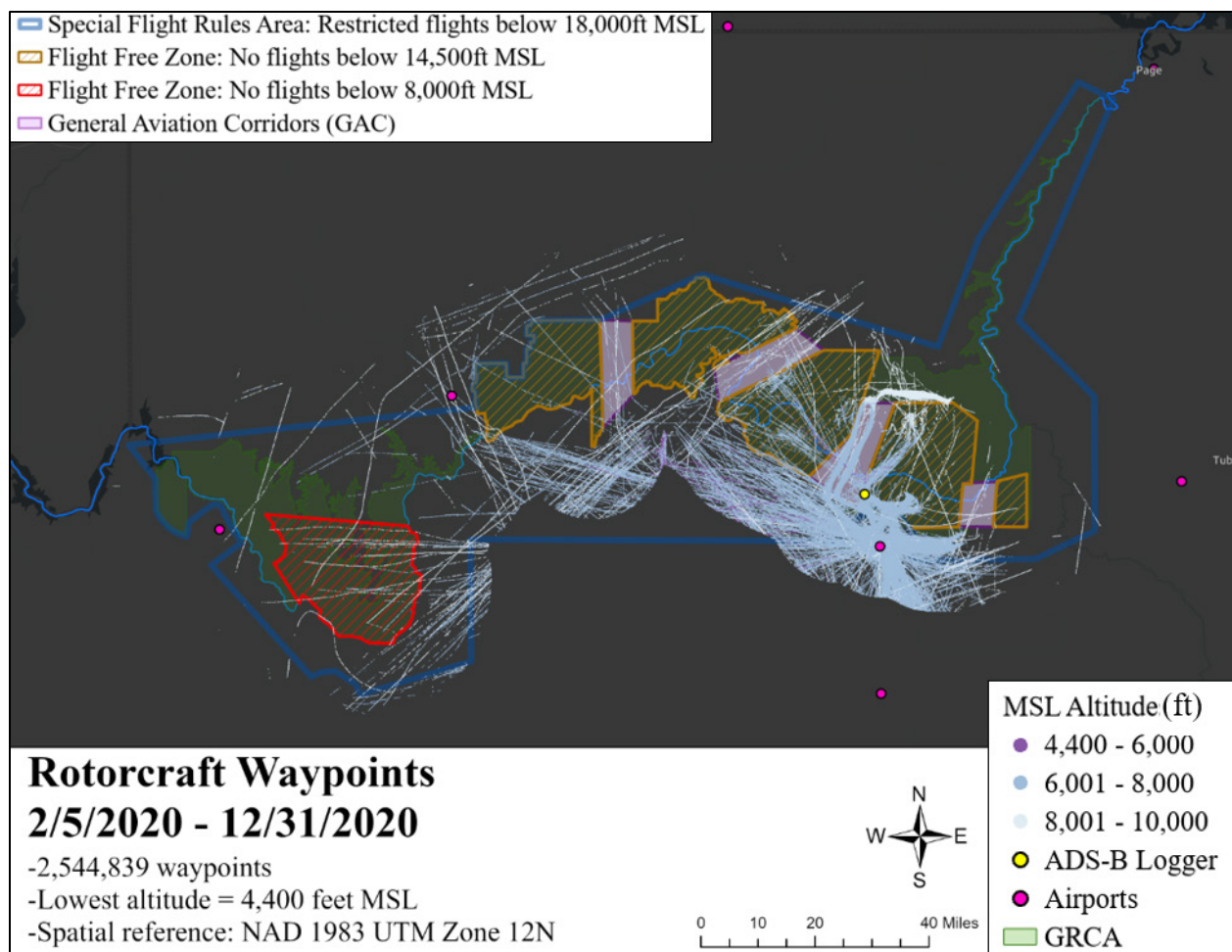


Figure 6. Rotorcraft waypoint MSL altitudes for February 5th, 2020 to December 31st, 2020.

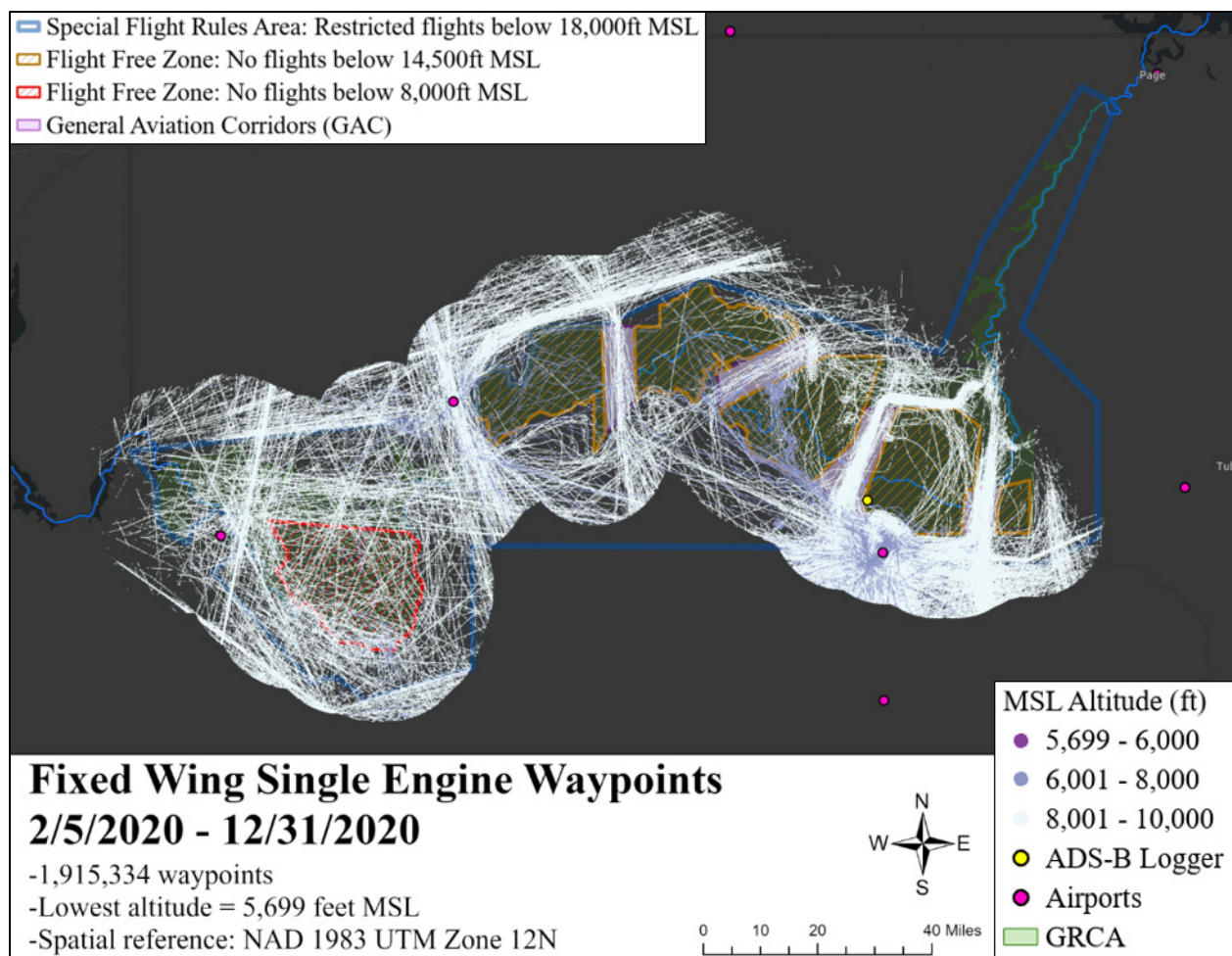


Figure 7. Fixed wing single engine waypoint MSL altitudes for February 5th, 2020 to December 31st, 2020.

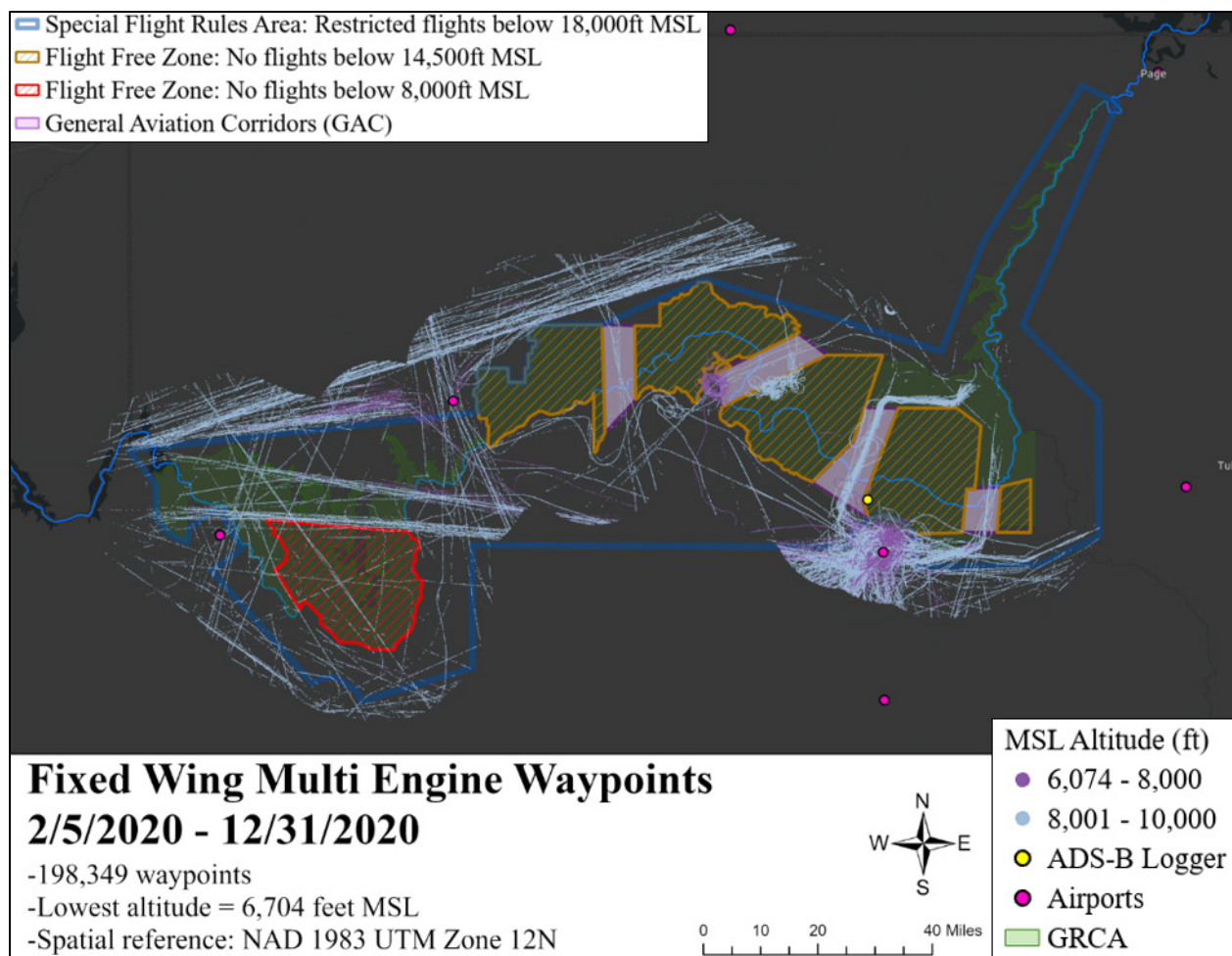


Figure 8. Fixed wing multi engine waypoint MSL altitudes for February 5th, 2020 to December 31st, 2020.

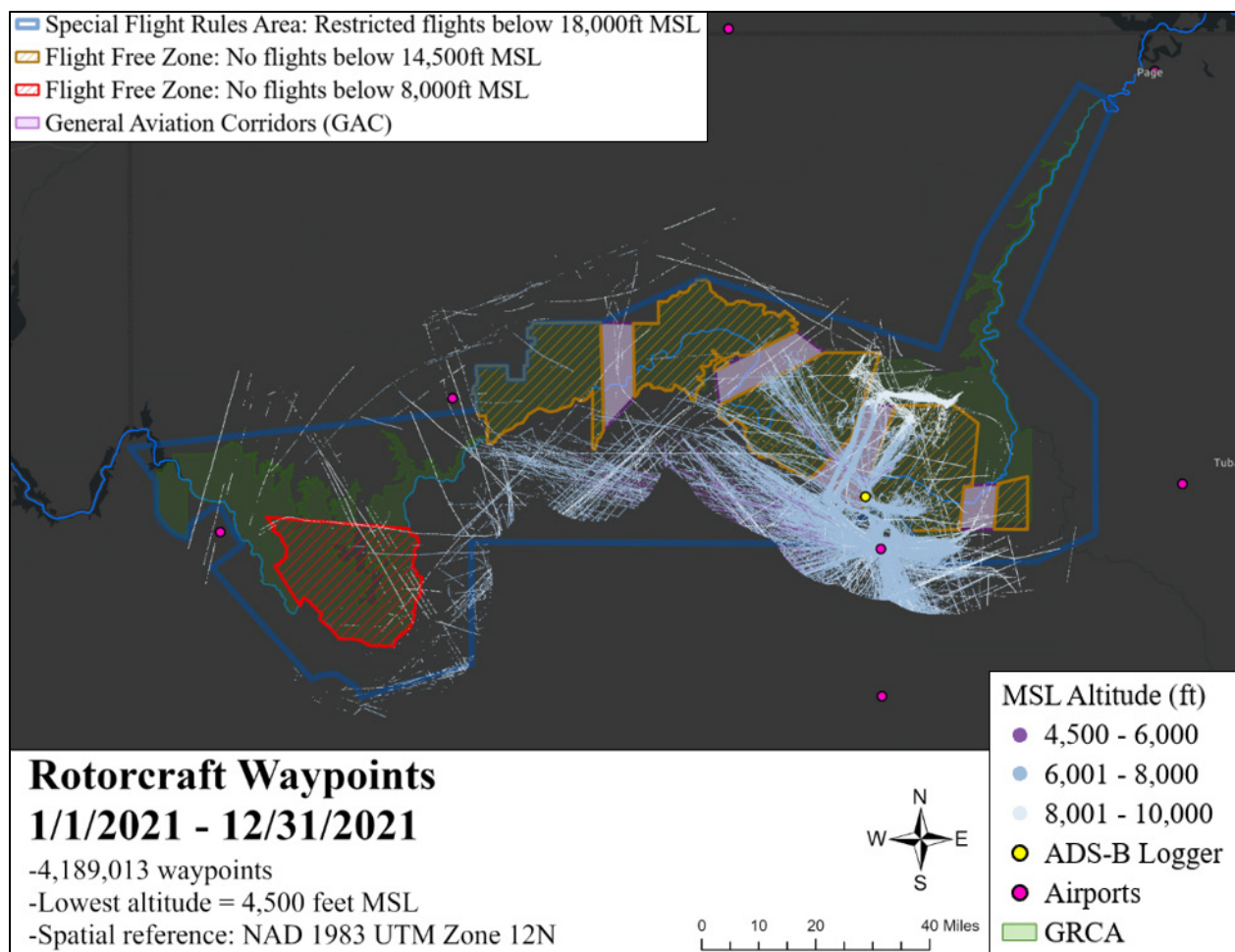


Figure 9. Rotorcraft waypoint MSL altitudes for January 1st, 2021 to December 31st, 2021.

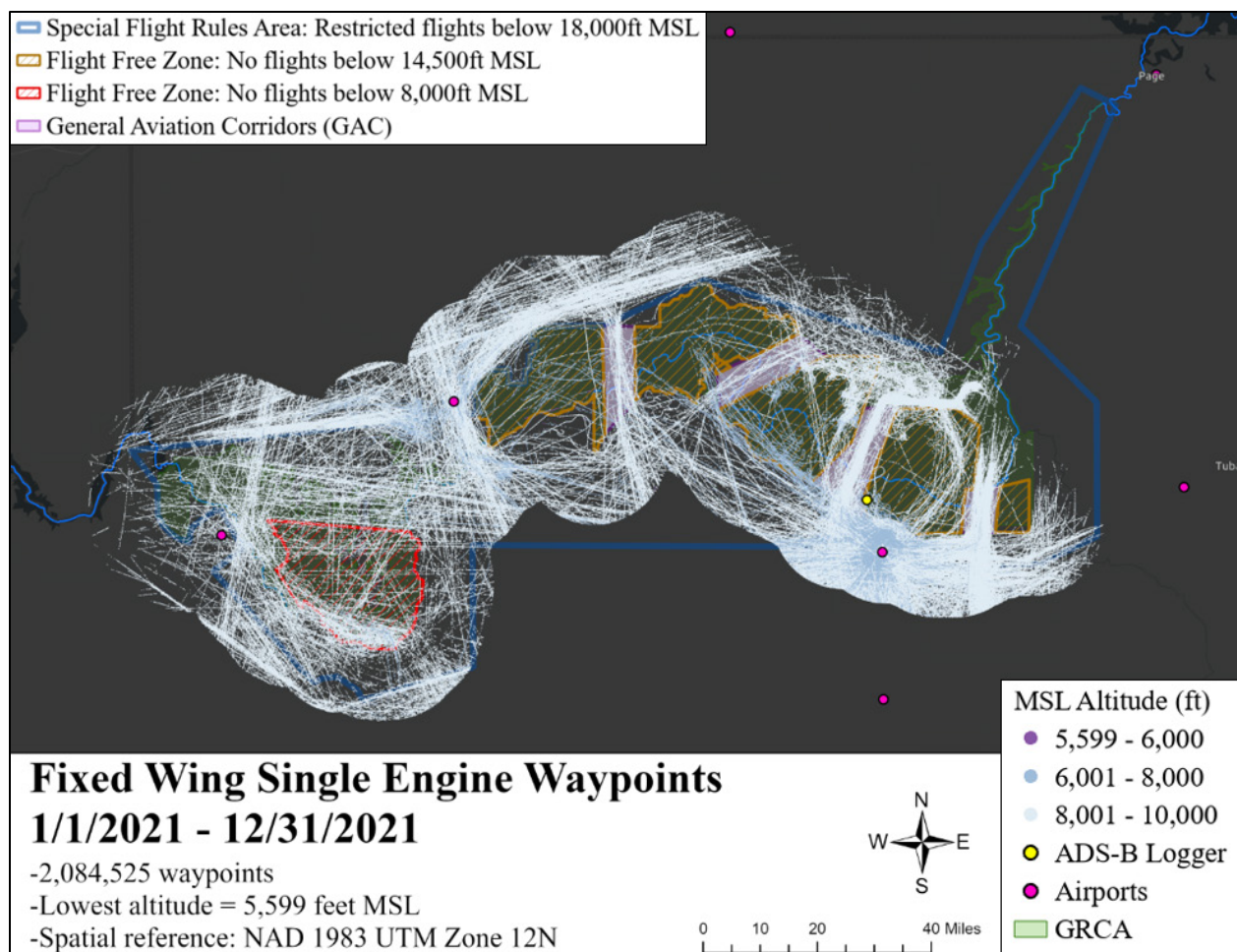


Figure 10. Fixed wing single engine waypoint MSL altitudes for January 1st, 2021 to December 31st, 2021.

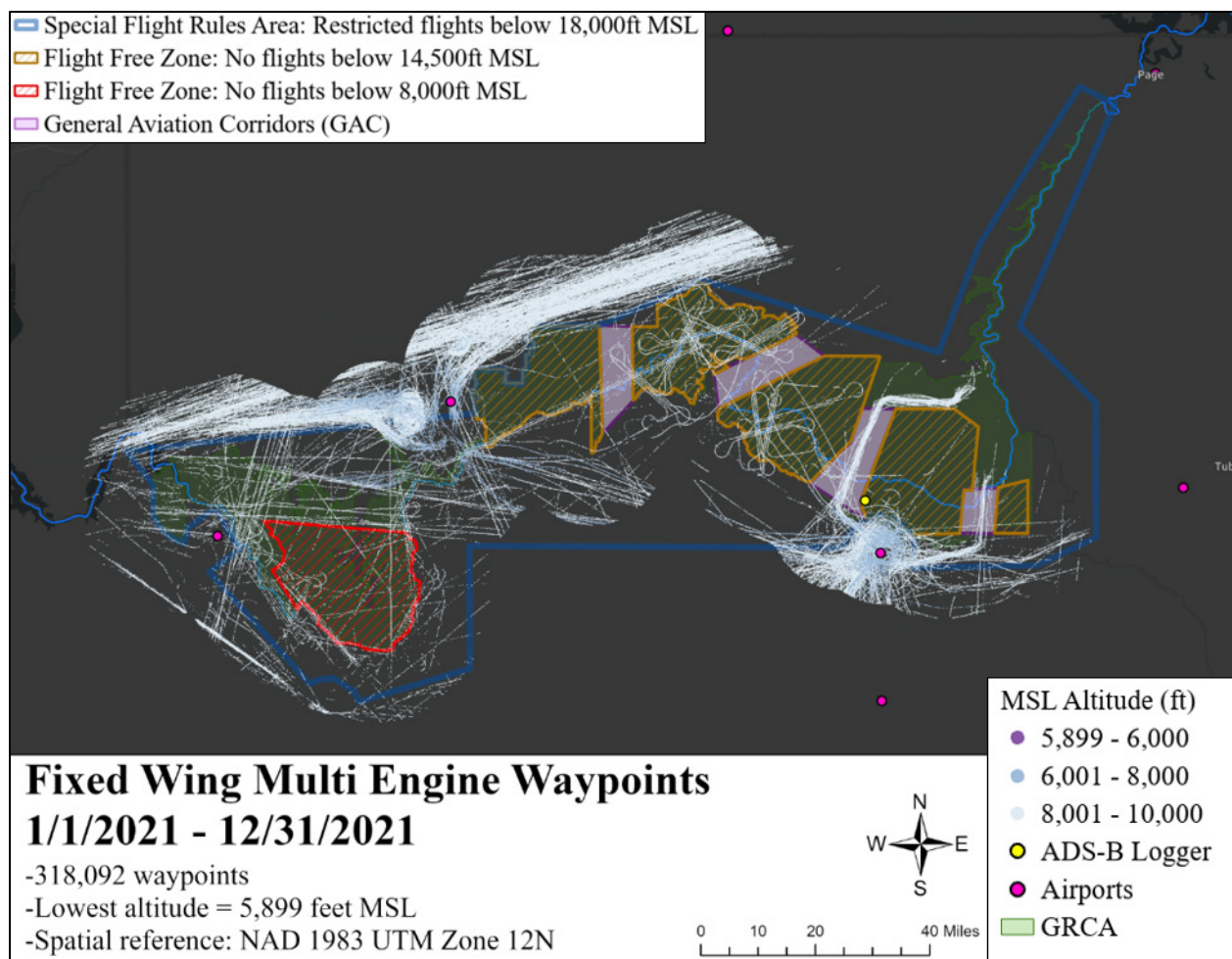


Figure 11. Fixed wing multi engine waypoint MSL altitudes for January 1st, 2021 to December 31st, 2021.

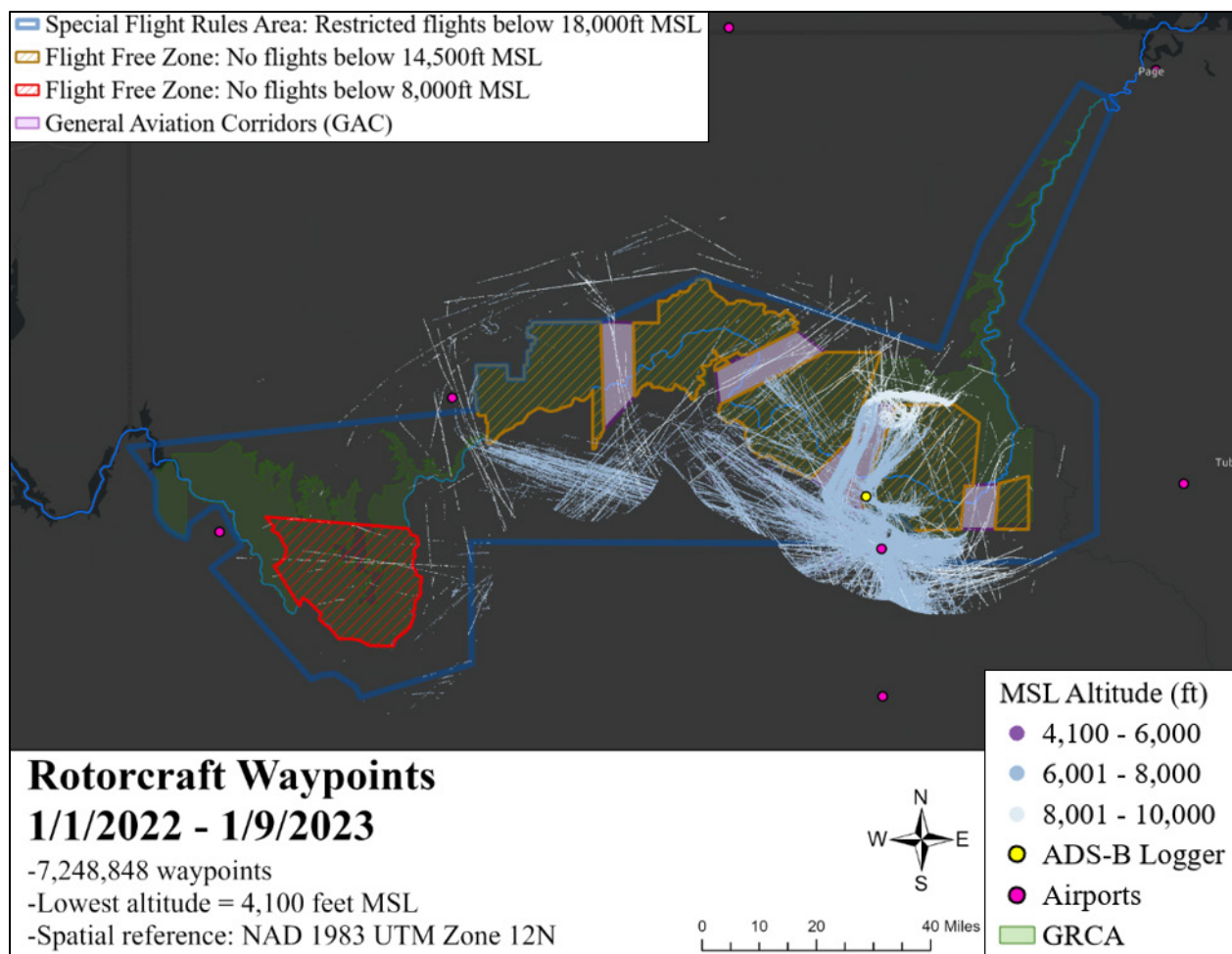


Figure 12. Rotorcraft waypoint MSL altitudes for January 1st, 2022 to January 9th, 2023.

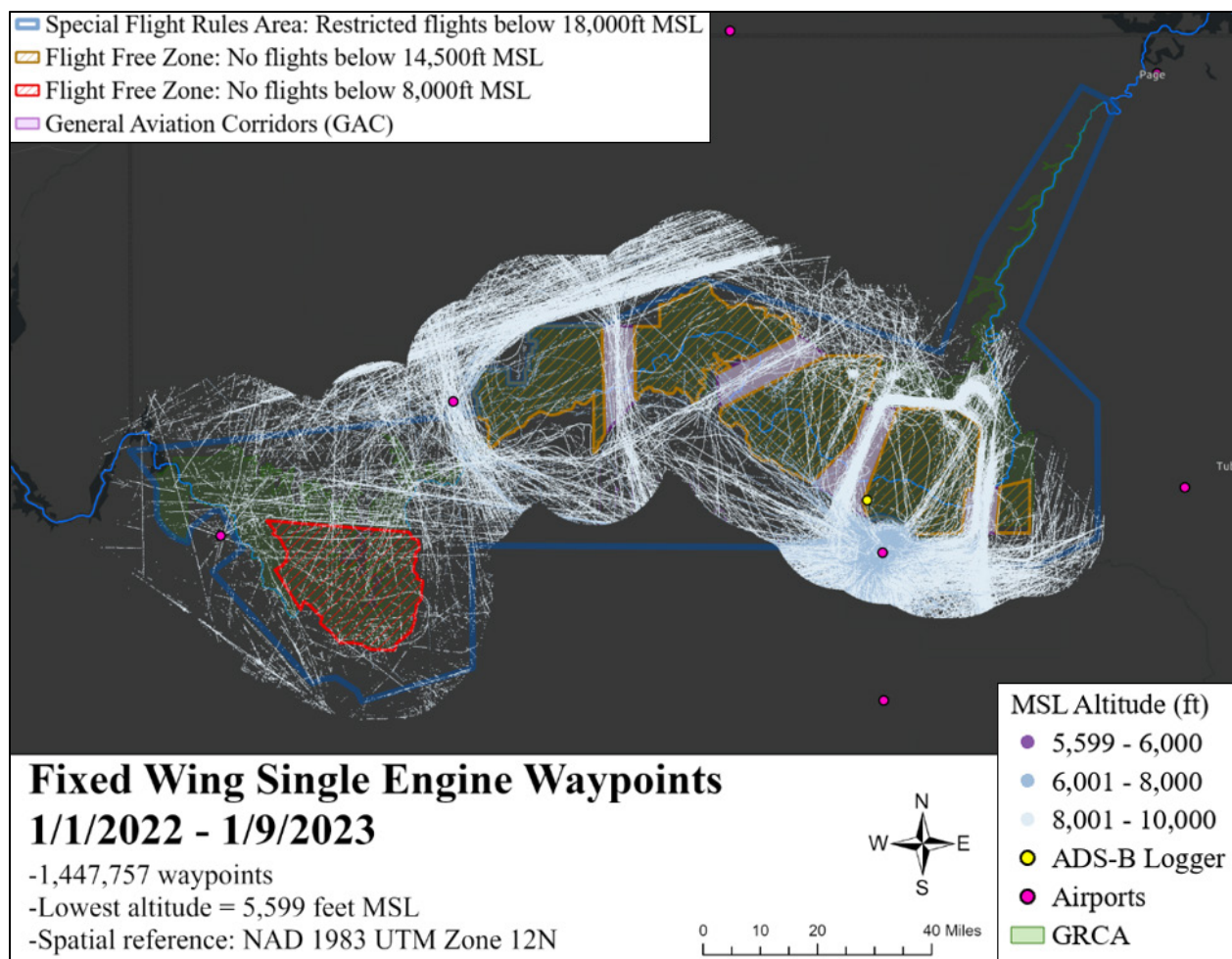


Figure 13. Fixed wing single engine waypoint MSL altitudes for January 1st, 2022 to January 9th, 2023.

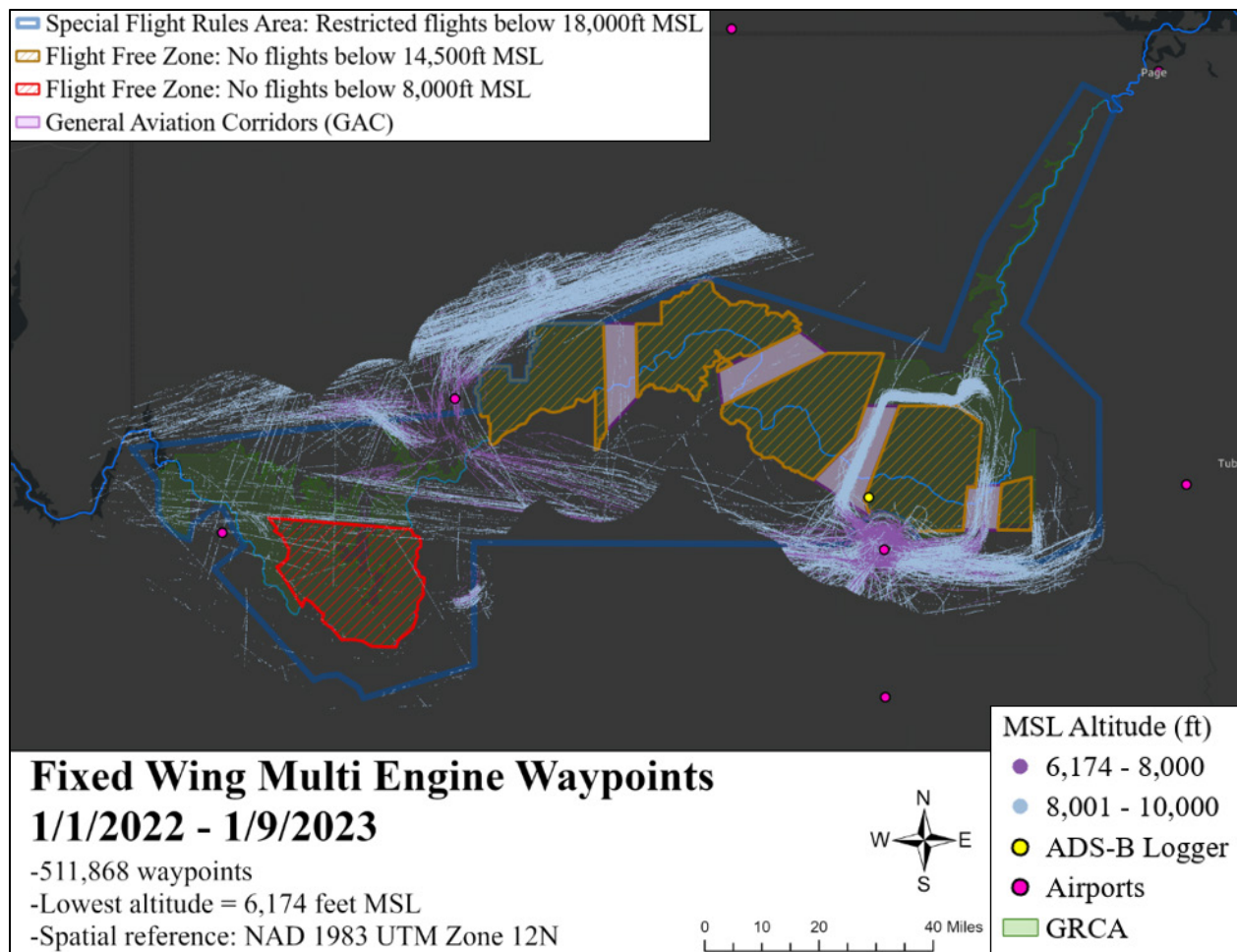


Figure 14. Fixed wing multi engine waypoint MSL altitudes for January 1st, 2022 to January 9th, 2023.

Results – Phase 3

Data were cleaned of all flights known to not be air tours, which resulted in the following numbers of flights removed: 2,191 civil patrol flights, 1,660 major airlines flights, 202,642 straight-line flights, 168 flights with a flightpath less than a mile in length, and two survey flights. This left 35,279 flights (Figure 15). Data for Phase 3 analysis were not segmented by year. Next, kernel density analysis was conducted across AGL altitude intervals up to 3,501 - 4,000 ft AGL. The AGL altitude interval that showed the most density was 3,001 - 3,500 ft. Figure 16 shows a density overview map, which displays waypoint densities up to 4,000 ft AGL. There were no density hot spots for 4,001 – 5,000 ft AGL. Figure 17 is zoomed in to show density hot spots for 0 – 2,000 ft AGL. Figure 18 is zoomed in to show density hot spots for 2,001 – 4,000 ft AGL. All density hotspots were located in the southeastern portion of the park near the ADS-B logger, which is the location of the Dragon Corridor and the Zuni Point Corridor.

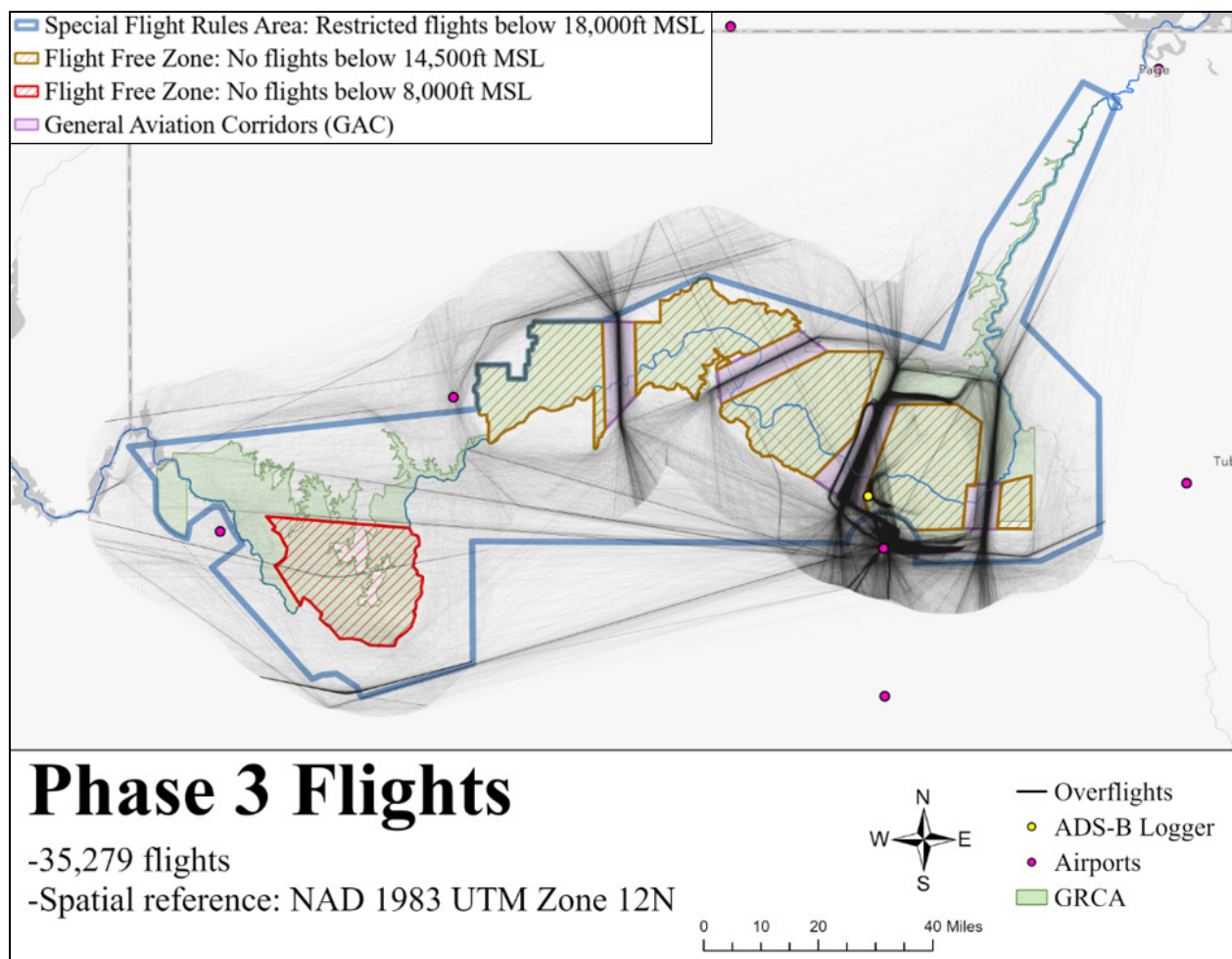


Figure 15. Overview of Phase 3 flights.

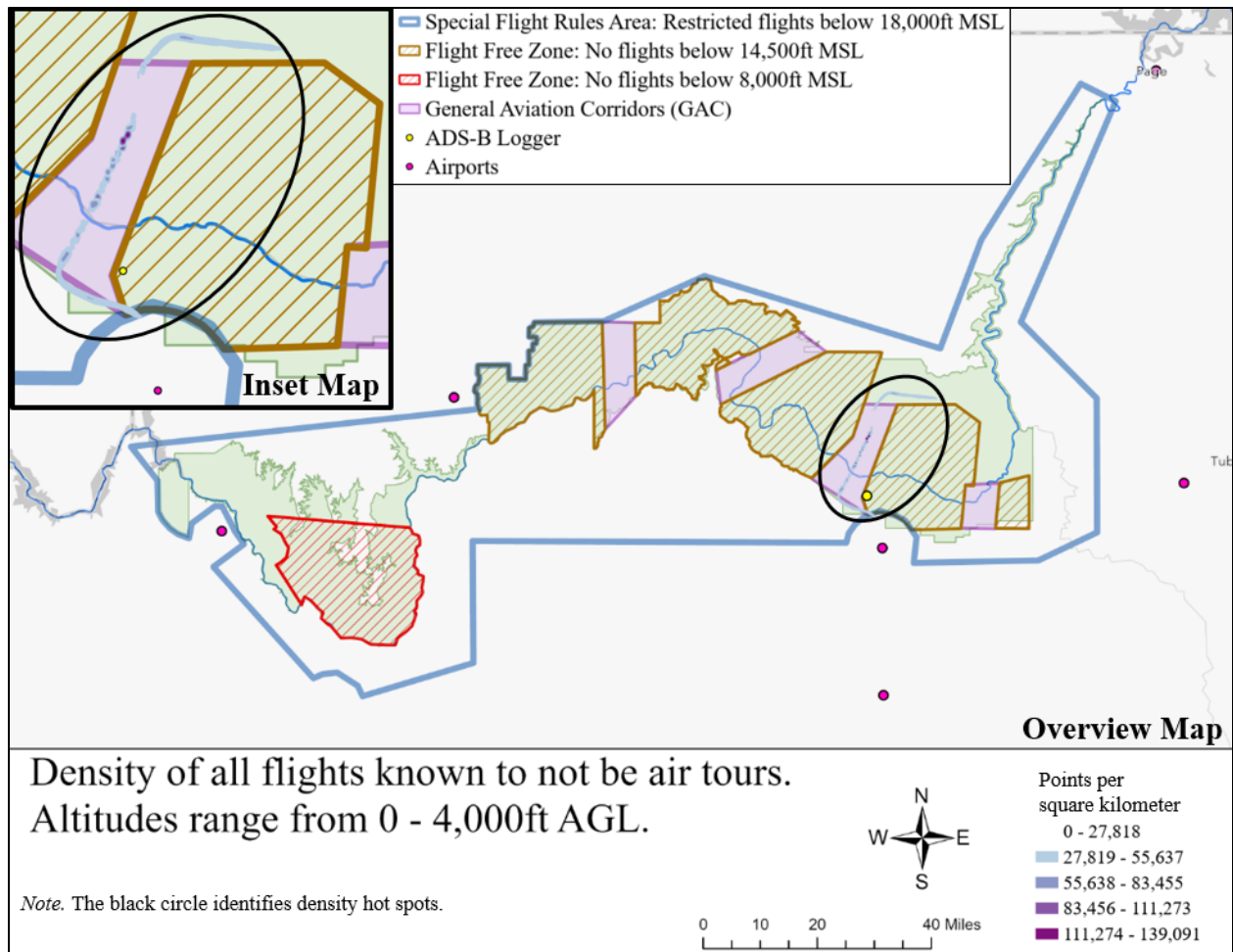


Figure 16. Overview of kernel density analysis showing AGL altitudes ranging from 0 – 4,000 ft.

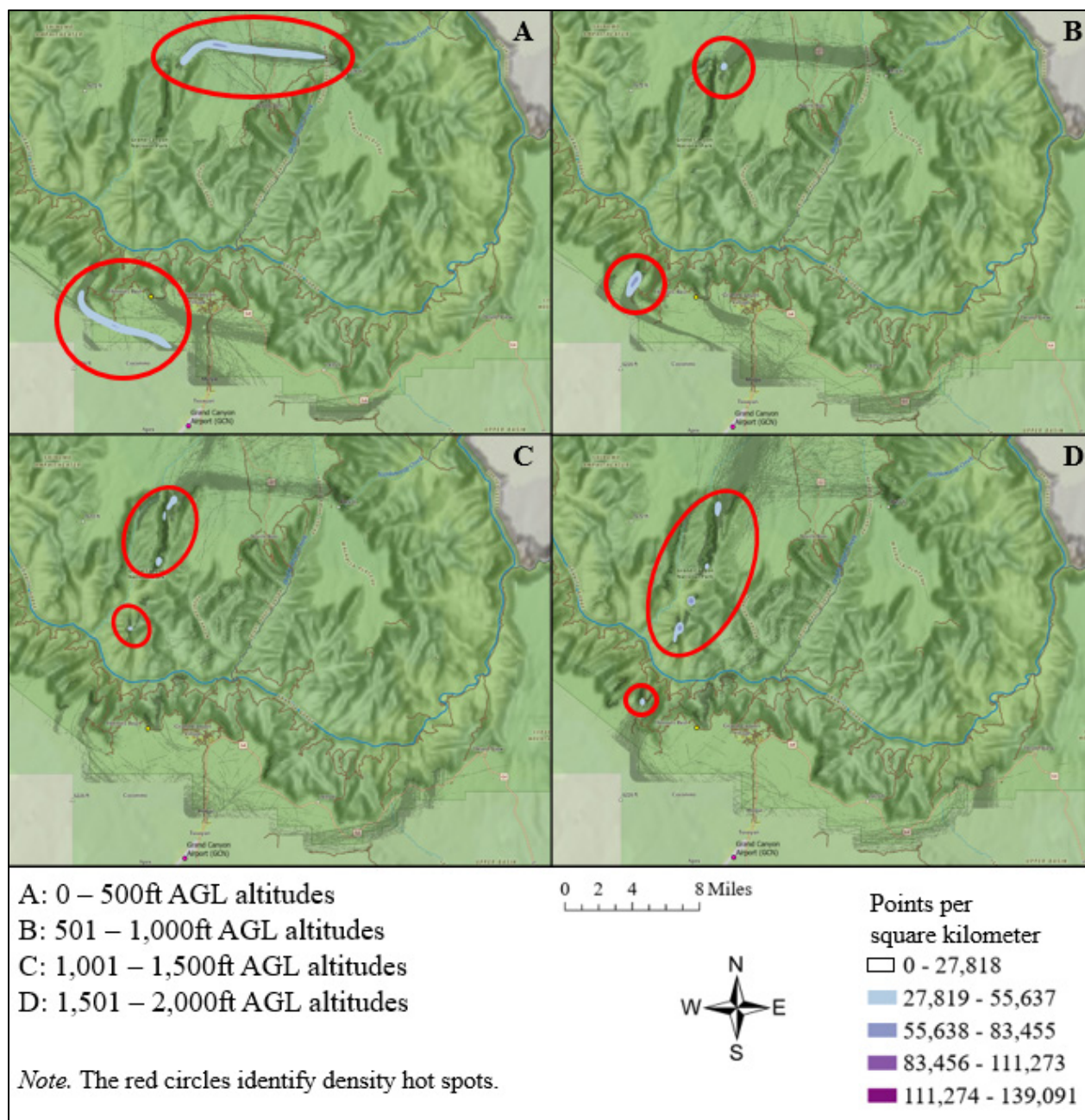


Figure 17. Kernel density analysis of 0 – 2,000 ft AGL altitudes.

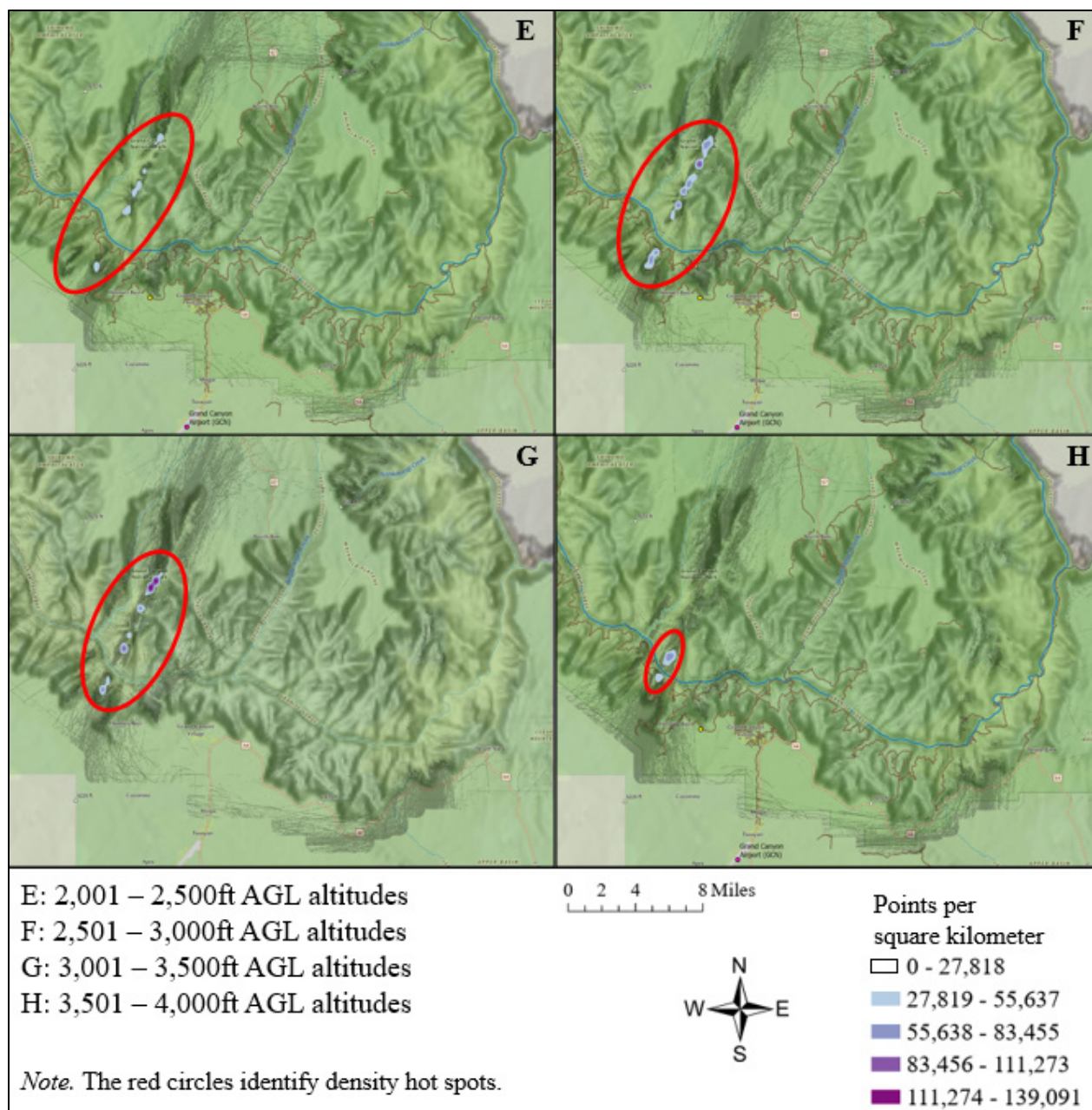


Figure 18. Kernel density analysis of 2,001 – 4,000 ft AGL altitudes.

The density outputs were statistically compared using a correlation test (Table 1). The altitude intervals with the highest correlation were 1,001 – 1,500 ft AGL and 1,501 – 2,000 ft AGL (correlation coefficient value = 0.70); and 1,501 – 2,000 ft AGL and 2,001 – 2,500 ft AGL (correlation coefficient value = 0.71). In general, for each column of the correlation matrix, as the altitude increases, the correlation coefficient value decreases.

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

AGL Altitude Interval	1.	2.	3.	4.	5.	6.	7.
1. 0 – 500 ft AGL	–	–	–	–	–	–	–
2. 501 – 1,000 ft AGL	0.56	–	–	–	–	–	–
3. 1,001 – 1,500 ft AGL	0.08	0.38	–	–	–	–	–
4. 1,501 – 2,000 ft AGL	0.04	0.17	0.70	–	–	–	–
5. 2,001 – 2,500 ft AGL	0.03	0.11	0.36	0.71	–	–	–
6. 2,501 – 3,000 ft AGL	0.02	0.03	0.10	0.31	0.67	–	–
7. 3,001 – 3,500 ft AGL	0.01	0.02	0.03	0.09	0.25	0.56	–
8. 3,500 – 4,000 ft AGL	0.03	0.05	0.04	0.06	0.11	0.17	0.30

To further understand altitude trends of waypoints, four visualizations were produced. Figures 19 (altitudes ranging from 0 - 2,500 ft AGL) and 20 (altitudes ranging from 2,501 - 5,000 ft AGL) display AGL altitude trends directly above GRCA and show variability in flight altitudes. Because the South Rim of GRCA is approximately 7,000 ft MSL (National Park Service, 2023), this elevation was used to segment the MSL data. Figures 21 (altitudes ranging from 0 – 7,000 ft MSL) and 22 (altitudes ranging from 7,001 – 10,000 ft MSL) display MSL altitude trends directly above GRCA and show waypoint altitudes trended between 6,000 – 10,000 ft MSL.

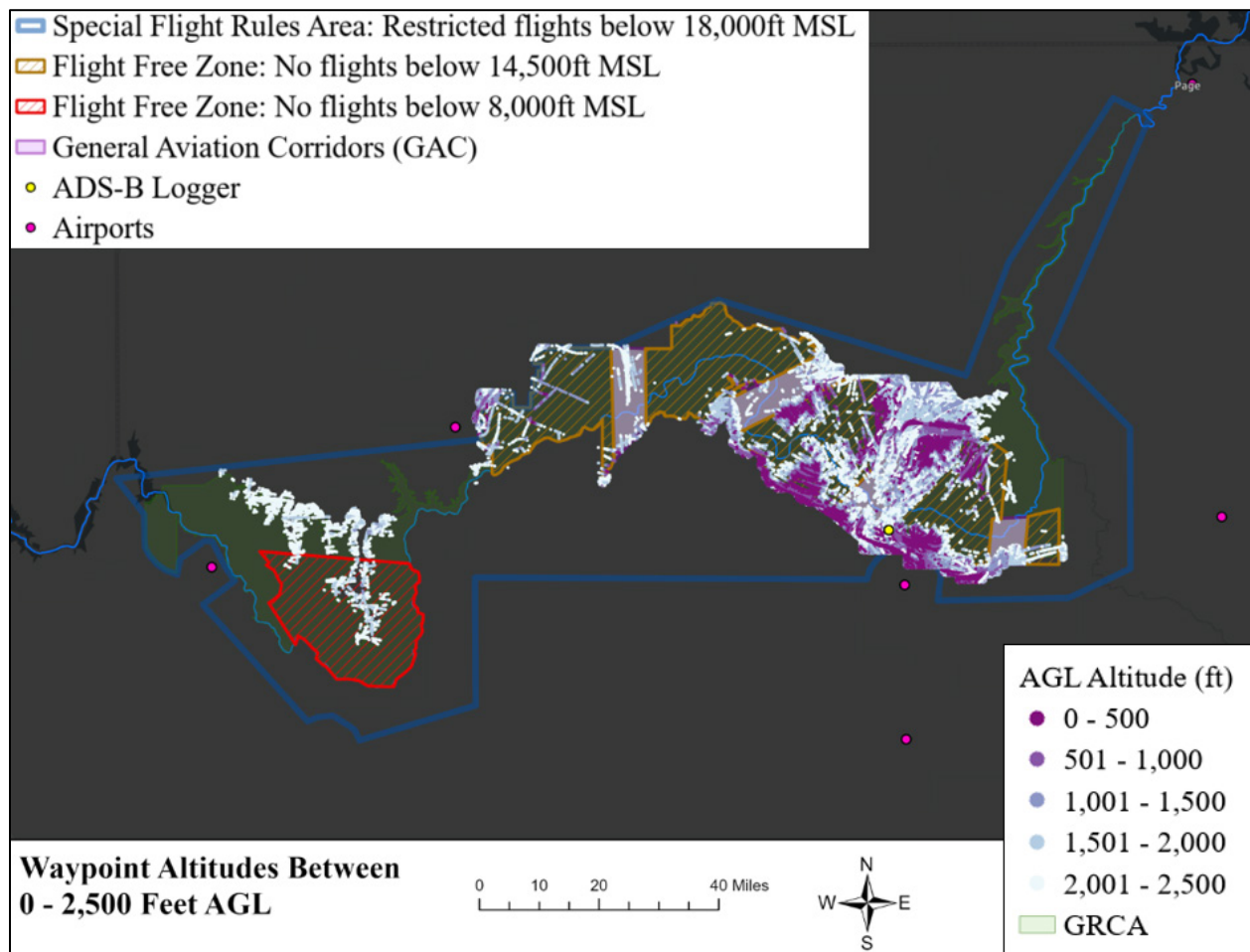


Figure 19. AGL altitude trends of altitudes ranging from 0 - 2,500 ft AGL for waypoints within 0.5-mile of the GRCA boundary ($n=2,259,187$ waypoints).

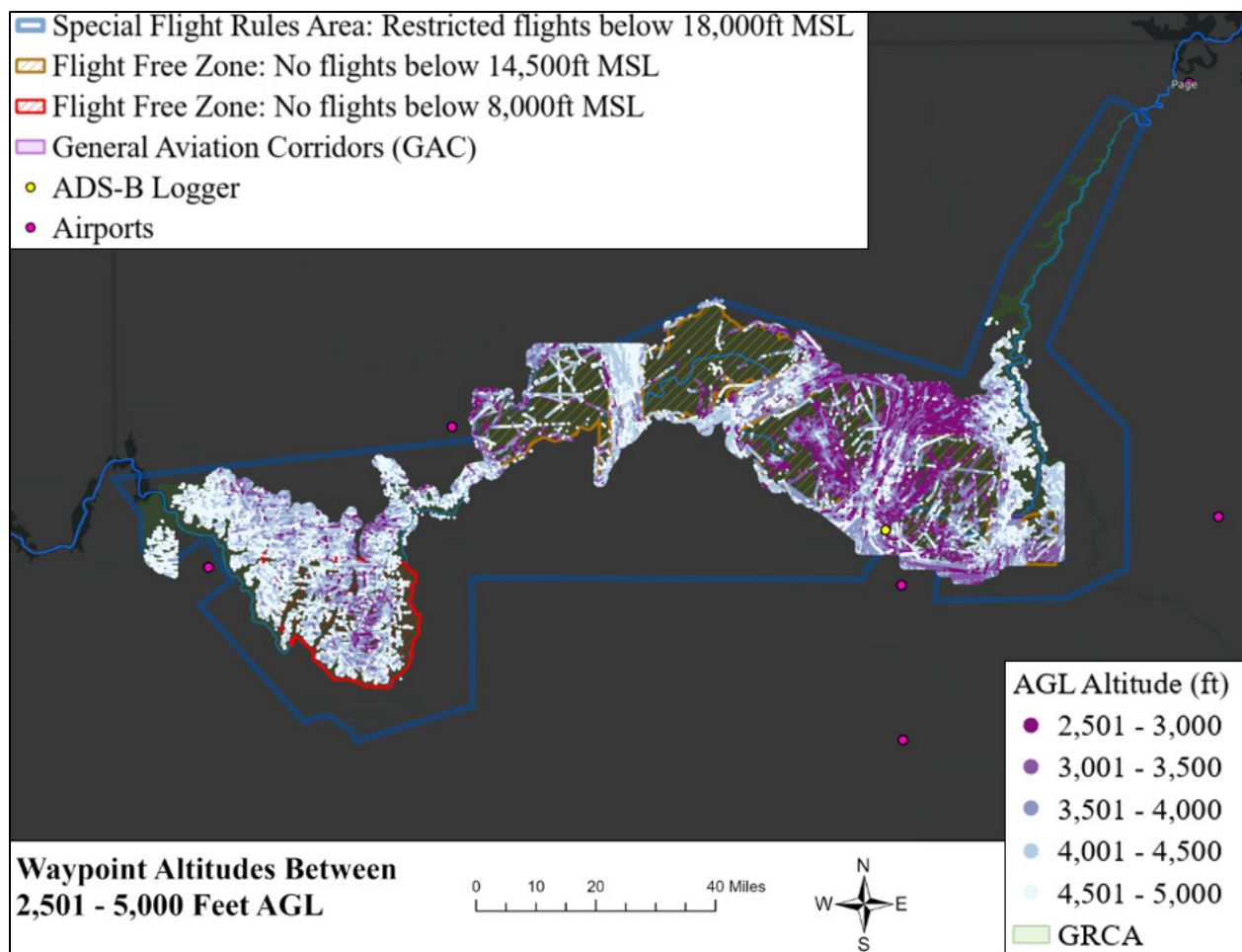


Figure 20. AGL altitude trends of altitudes ranging from 2,501 - 5,000 ft AGL for waypoints within 0.5-mile of the GRCA boundary ($n=1,953,819$ waypoints).

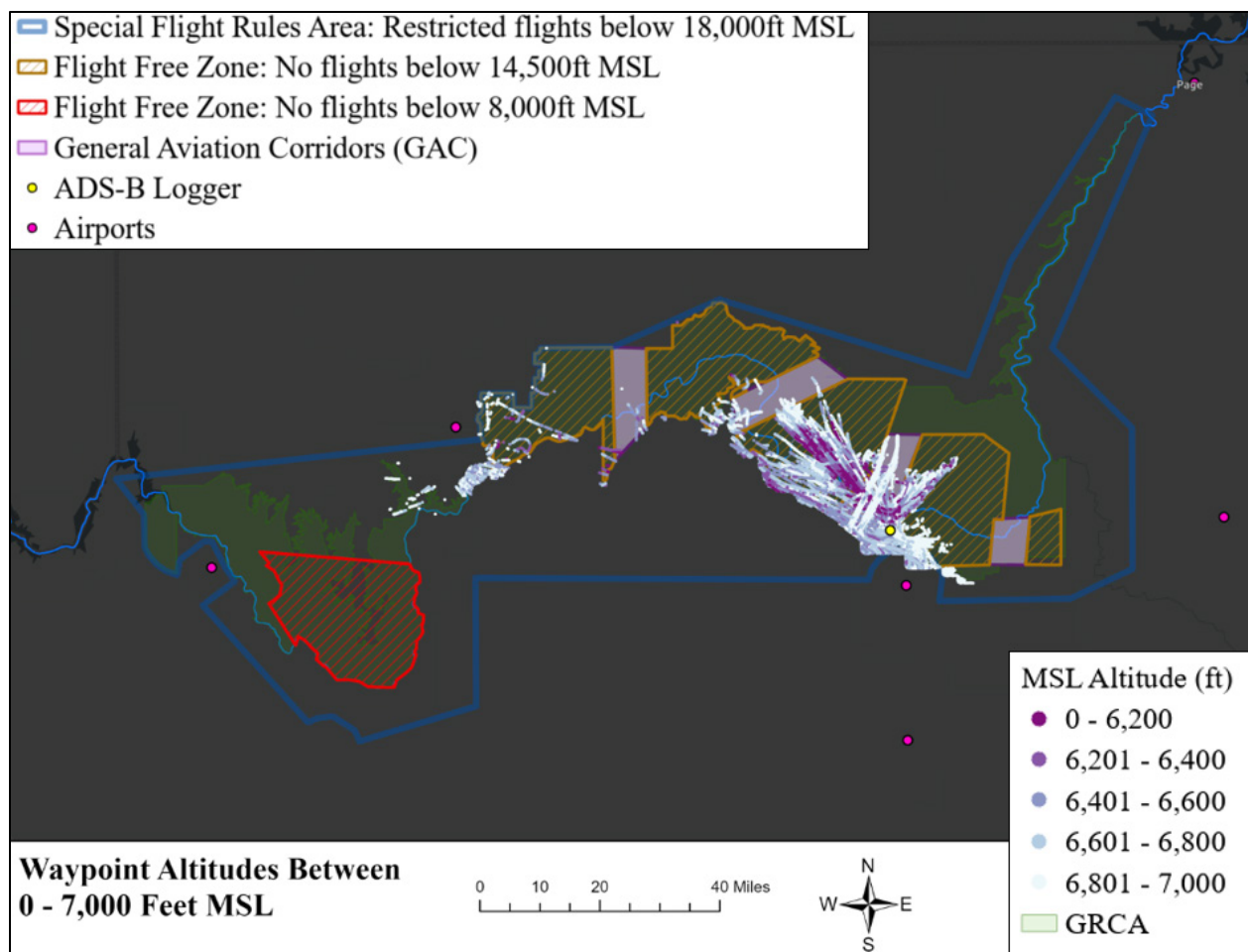


Figure 21. MSL altitude trends of altitudes ranging from 0 – 7,000 ft MSL for waypoints within 0.5-mile of the GRCA boundary ($n=1,683,593$ waypoints).

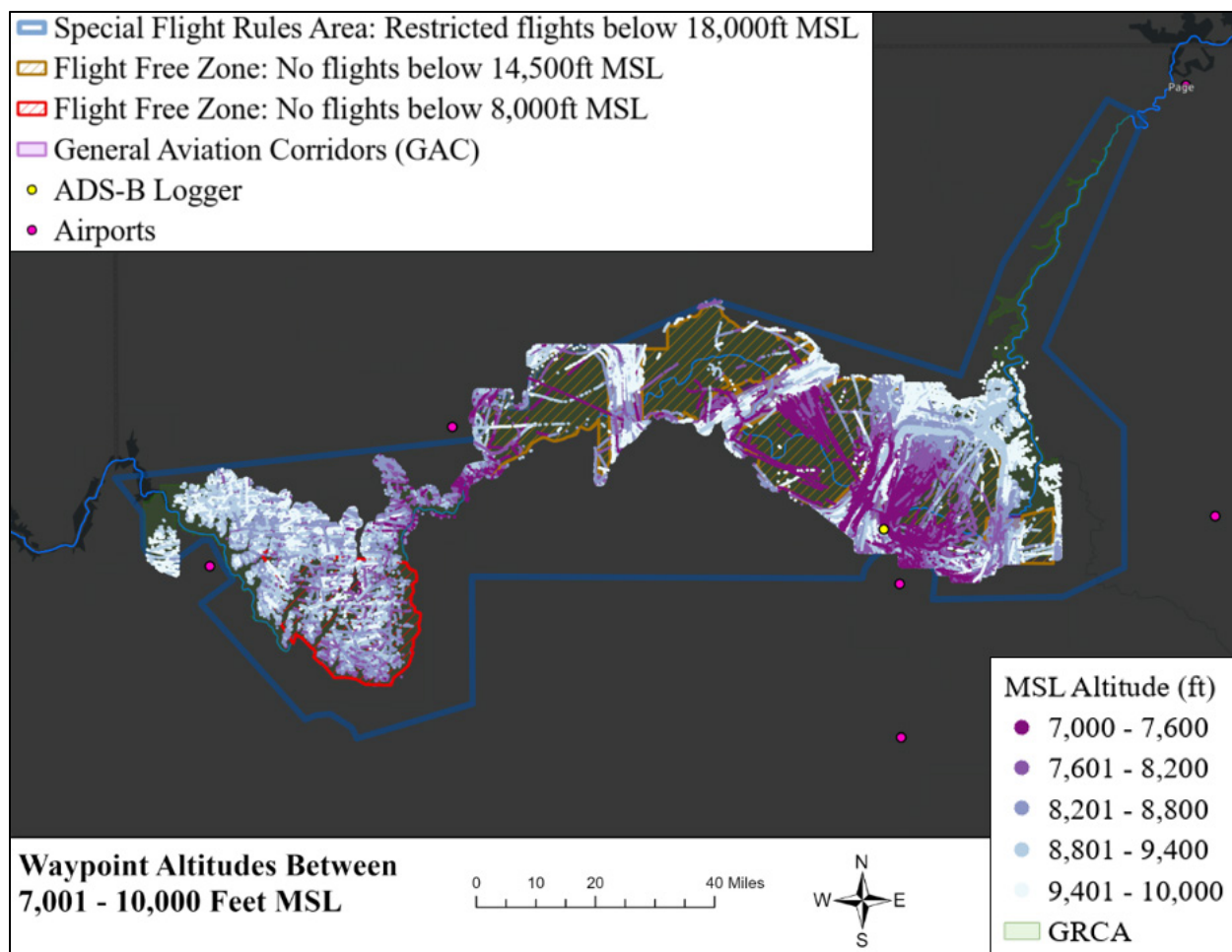


Figure 22. MSL altitude trends of altitudes ranging from 7,001 - 10,000 ft MSL for waypoints within 0.5-mile of the GRCA boundary ($n=3,713,392$ waypoints).

The information displayed in Figures 19, 20, 21, and 22 were inputted into tables to quantitatively understand which altitude intervals had the highest percentage of waypoints. Table 2 shows analysis of 4,213,006 waypoints across AGL altitudes and Table 3 shows analysis of 5,396,985 waypoints across MSL altitudes. The AGL altitude interval that received the highest percentage of waypoints was 0 – 500 ft (Table 2), but note that the following altitude intervals had a significant number of waypoints: 501 – 1,000 ft AGL; 2,501 – 3,000 ft AGL; and 3,001 – 3,500 ft AGL. The MSL altitude interval that received the highest percentage of waypoints was 7,001-8,000 ft (Table 3), but note that the following altitude intervals had a significant number of waypoints: 6,001 – 7,000 ft MSL and 8,001 – 9,000 ft MSL.

Next, overflights were analyzed across months, days of the week, and hours of the day (total flights analyzed = 35,279). Table 4 shows number of days air tour data were collected, overflights per month, and average number of flights per day for the data collection duration, which occurred from February 5th, 2020 to January 9th, 2023. GRCA received the most overflights during July of 2022 (68.52 average number of flights per day).

Table 2. Number and percentage of waypoints across AGL altitude intervals ($n=4,213,006$).

AGL altitude	Number of waypoints	Percentage of waypoints
0-500 ft	625,948	14.86
501-1,000 ft	574,280	13.63
1,001-1,500 ft	294,821	7.00
1,501-2,000 ft	383,428	9.10
2,001-2,500 ft	380,710	9.04
2,501-3,000 ft	530,218	12.59
3,001-3,500 ft	444,923	10.56
3,501-4,000 ft	341,449	8.10
4,001-4,500 ft	328,339	7.79
4,501-5,000 ft	308,891	7.33

Table 3. Number and percentage of waypoints across MSL altitude intervals ($n=5,396,985$).

MSL altitude	Number of waypoints	Percentage of waypoints
0-1,000 ft	0	0.00
1,001-2,000 ft	0	0.00
2,001-3,000 ft	13	0.00
3,001-4,000 ft	21	0.00
4,001-5,000 ft	1,611	0.03
5,001-6,000 ft	16,117	0.30
6,001-7,000 ft	1,665,831	30.87
7,001-8,000 ft	1,834,703	33.99
8,001-9,000 ft	1,540,884	28.55
9,001-10,000 ft	337,805	6.26

Table 4. Number and percentage of overflights across months ($n=35,279$).

Month	Number of data collection days*	Number of overflights	Average Number of overflights per day
February 2020	25	667	26.68
March 2020	31	522	16.84
April 2020	30	228	7.60
May 2020	31	369	11.90

*For some months, data collection did not occur everyday because technological failure.

Table 4 (continued). Number and percentage of overflights across months ($n=35,279$).

Month	Number of data collection days*	Number of overflights	Average Number of overflights per day
June 2020	30	714	23.80
July 2020	31	927	29.90
August 2020	31	765	24.68
September 2020	30	1064	35.47
October 2020	31	1195	38.55
November 2020	30	878	29.27
December 2020	31	613	19.77
January 2021	31	574	18.52
February 2021	28	649	23.18
March 2021	31	1068	34.45
April 2021	30	1408	46.93
May 2021	31	1505	48.55
June 2021	30	1769	58.97
July 2021	15	666	44.40
August 2021	29	1271	43.83
September 2021	30	1505	50.17
October 2021	28	1217	43.46
November 2021	3	47	15.67
December 2021	31	526	16.97
January 2022	31	705	22.74
February 2022	1	27	27.00
March 2022	29	1285	44.31
April 2022	12	598	49.83
May 2022	31	1495	48.23
June 2022	30	1774	59.13
July 2022	31	2124	68.52
August 2022	31	2063	66.55
September 2022	30	1818	60.60
October 2022	31	1571	50.68
November 2022	30	915	30.50
December 2022	31	617	19.90
January 2023	9	140	15.56
Total	837	35,279	16.64

*For some months, data collection did not occur everyday because technological failure.

Table 5 shows percentage of flights across days of the week. The day of the week with the highest percentage of flights was Saturdays (15.50%). Table 6 shows percentage of overflights across hour of the day for when air tours are permitted. Most overflights occur from 9:00am to 12:00pm. Table 7 shows percentage of overflights across aircraft type. Rotorcraft is the aircraft type most common among overflights at GRCA.

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

Day of the week	Percent of overflights
Monday	13.90
Tuesday	12.90
Wednesday	13.90
Thursday	14.20
Friday	14.40
Saturday	15.50
Sunday	15.10

Table 6. Number and percentage of overflights across hours of the day for weekdays ($n=24,488$) and weekends ($n=10,791$).

Hour	Percentage of overflights
:00am-7:00am	0.70
7:00am-8:00am	1.60
8:00am-9:00am	7.70
9:00am-10:00am	14.00
10:00am-11:00am	12.40
11:00am-12:00pm	12.60
12:00pm-1:00pm	9.00
1:00pm-2:00pm	9.80
2:00pm-3:00pm	10.00
3:00pm-4:00pm	8.70
4:00pm-5:00pm	7.20
5:00pm-6:00pm	4.70
6:00pm-7:00pm	1.00
7:00-8:00pm	0.40

Table 7. Percentage of overflights across aircraft type.

Aircraft type	Percentage
Fixed-wing single engine	25.60
Fixed-wing multi engine	4.50
Rotorcraft	58.40

Using the cleaned Phase 3 dataset comprised of all four years of data, three more figures were produced to show overflight travel patterns across aircraft type. Figure 23 displays overflight travel patterns for rotorcraft. Figure 24 displays overflight travel patterns for fixed wing single engine aircraft. Figure 25 displays overflight travel patterns for fixed wing multi engine aircraft.

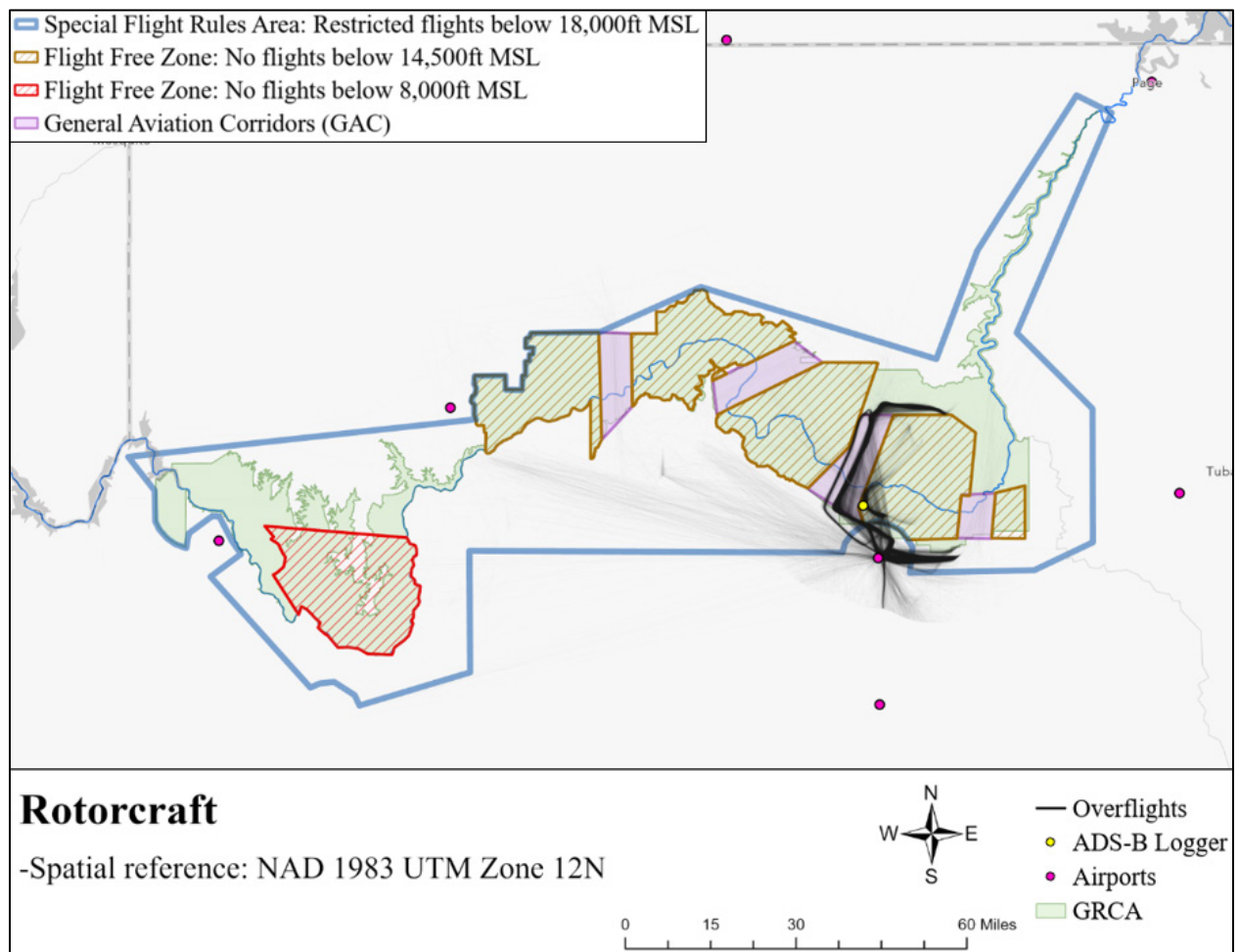


Figure 23. Phase 3 rotorcraft overflight travel patterns.

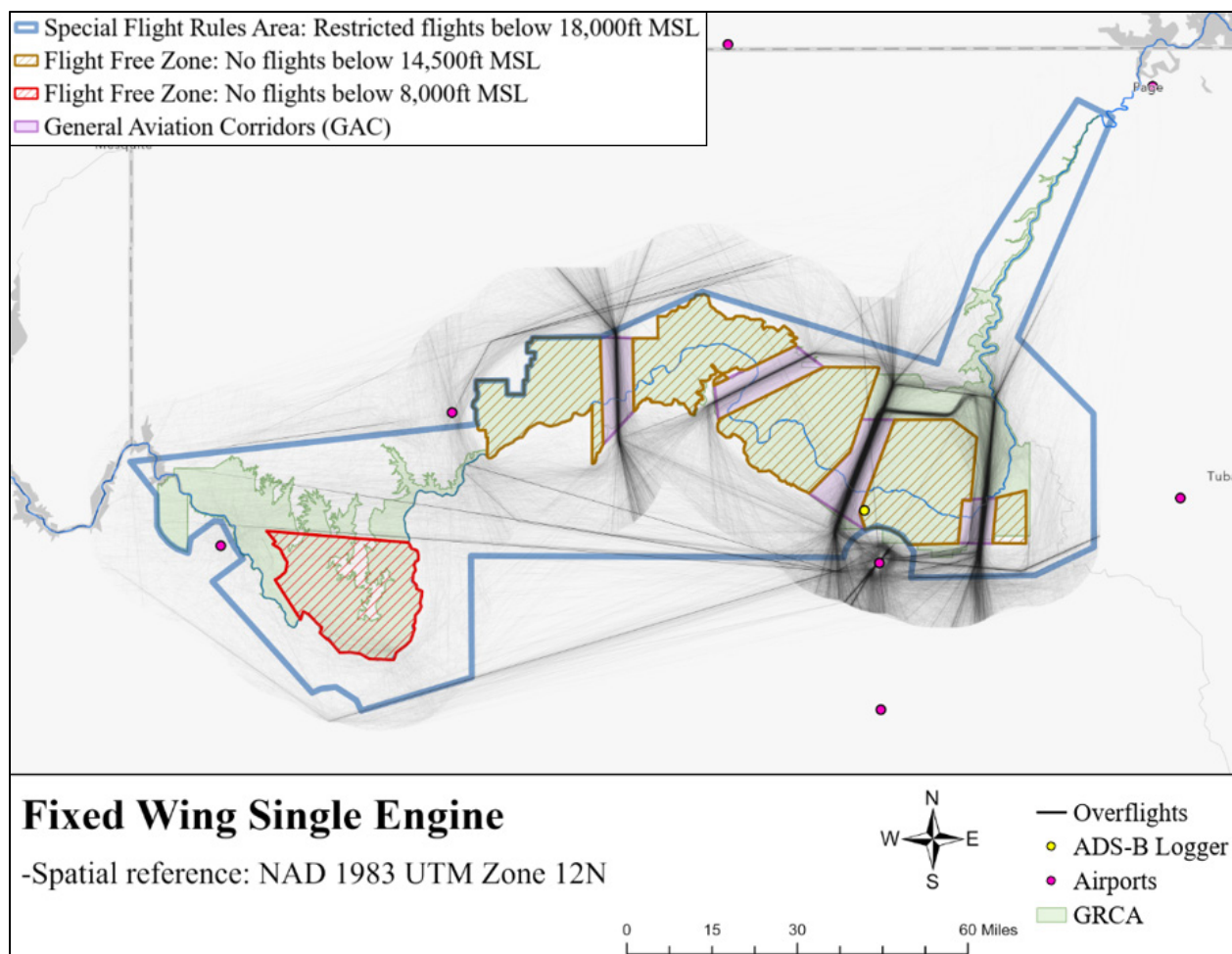


Figure 24. Phase 3 fixed wing single engine overflight travel patterns.

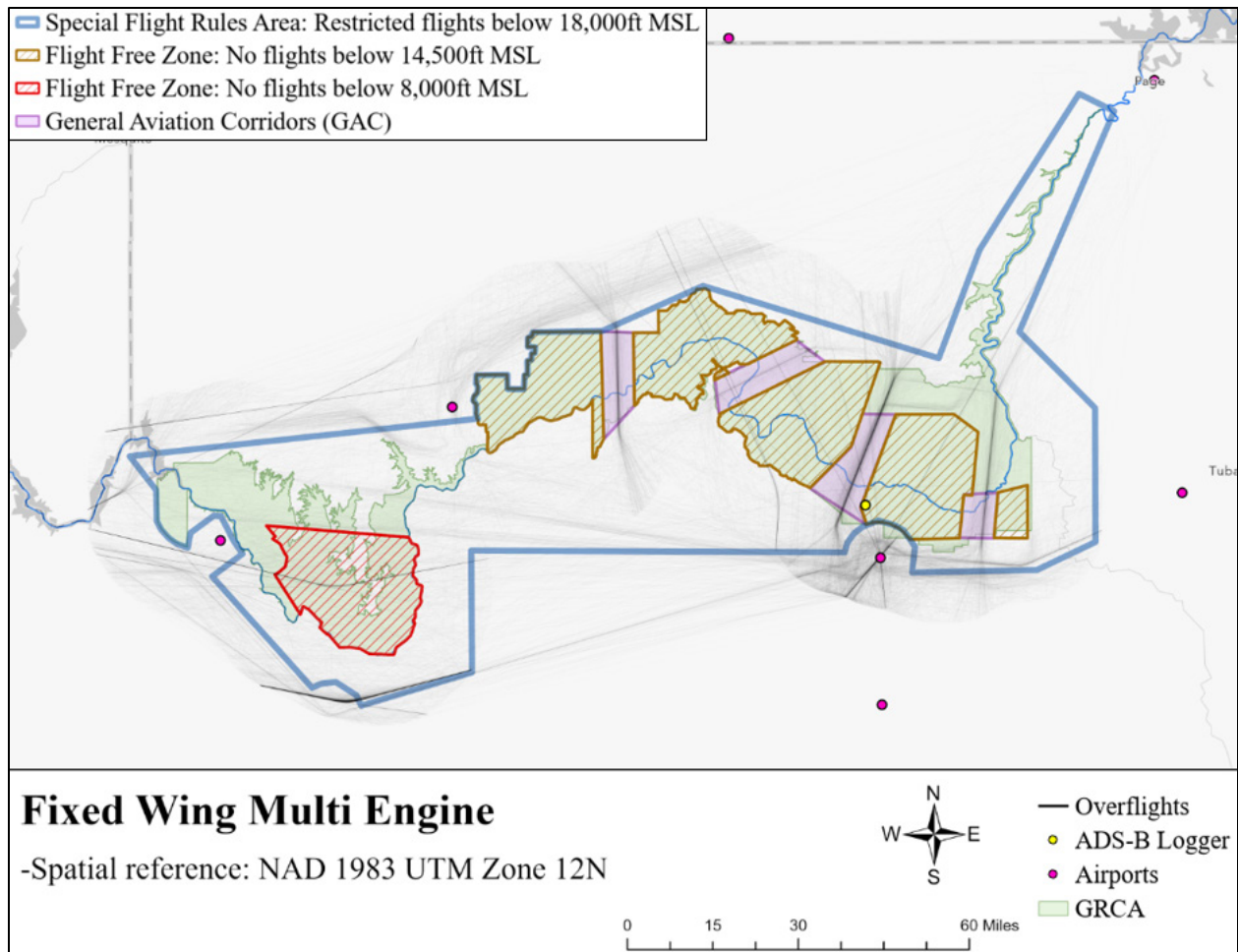


Figure 25. Phase 3 fixed wing multi engine overflight travel patterns.

Figures were also produced for operators that conducted the most overflights regardless of aircraft type. Major air tour operators often own multiple aircraft and each aircraft has a unique tail number. For each operator, flights were compiled across all of their tail numbers. A 10-mile buffer around the GRCA perimeter was applied to gain a better understanding of flight routes. Figure 26 displays Papillon Airways. Figure 27 displays Maverick Helicopters. Figure 28 displays Grand Canyon Airlines.

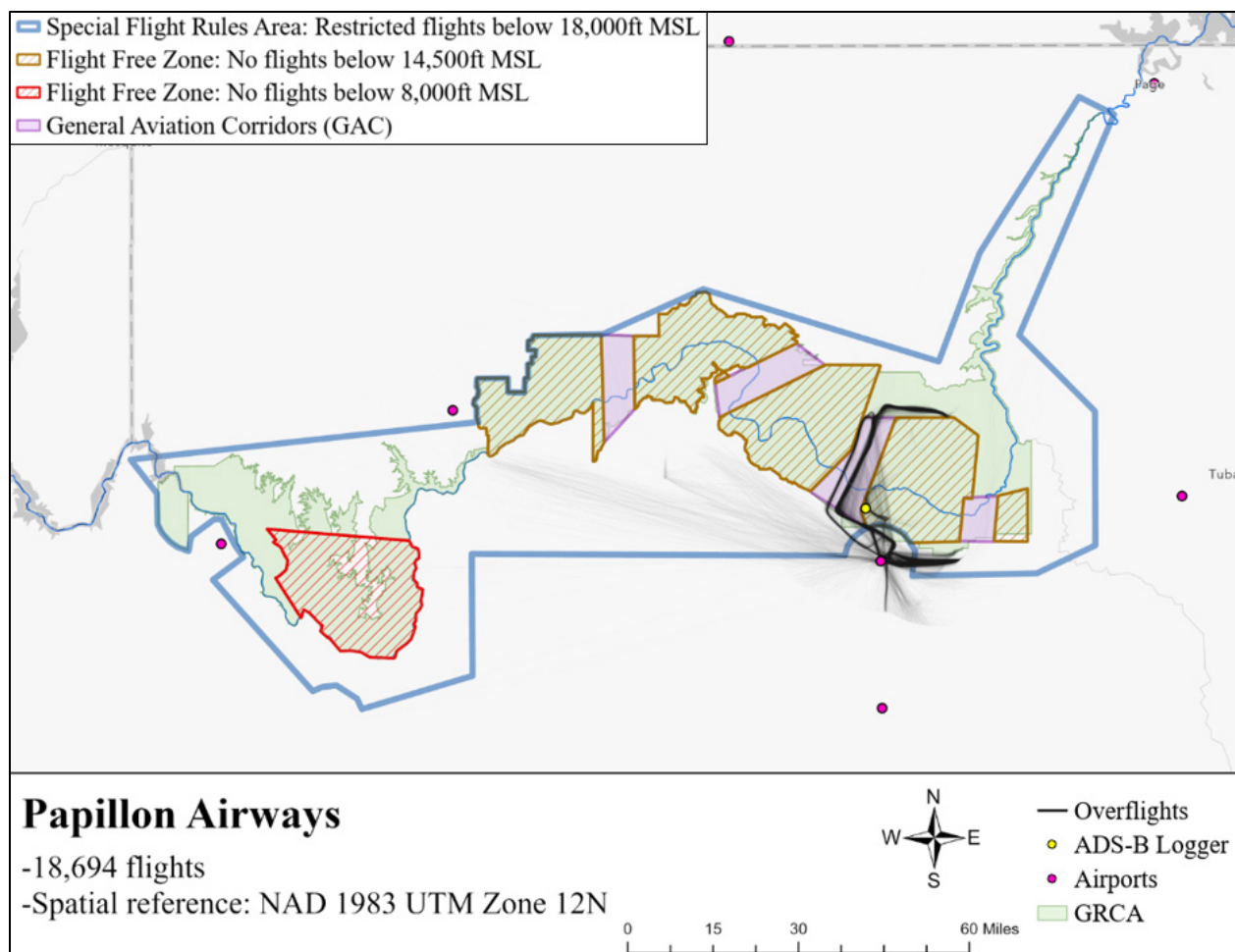


Figure 26. Overflight travel patterns for Papillon Airways.

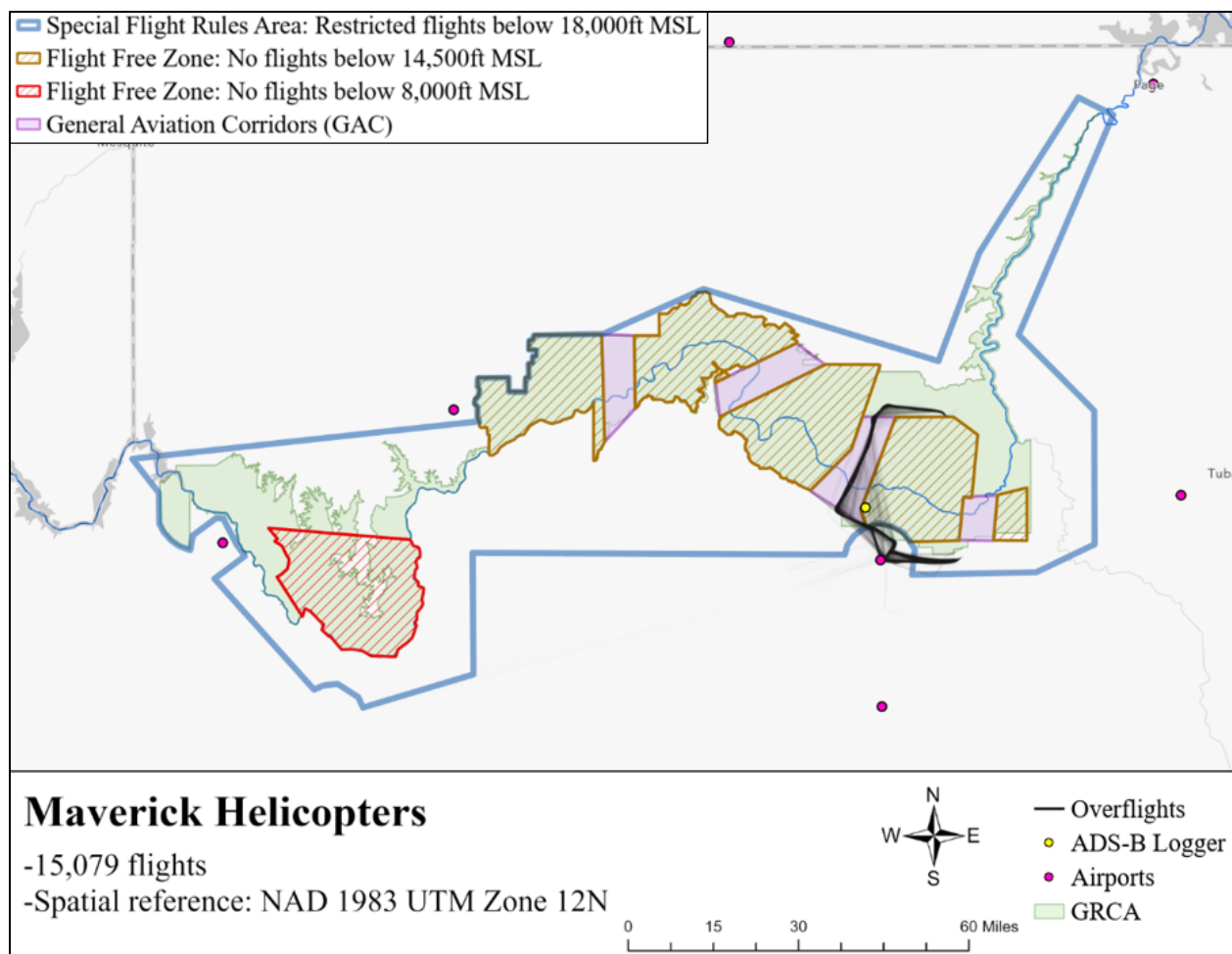


Figure 27. Overflight travel patterns for Maverick Helicopters.

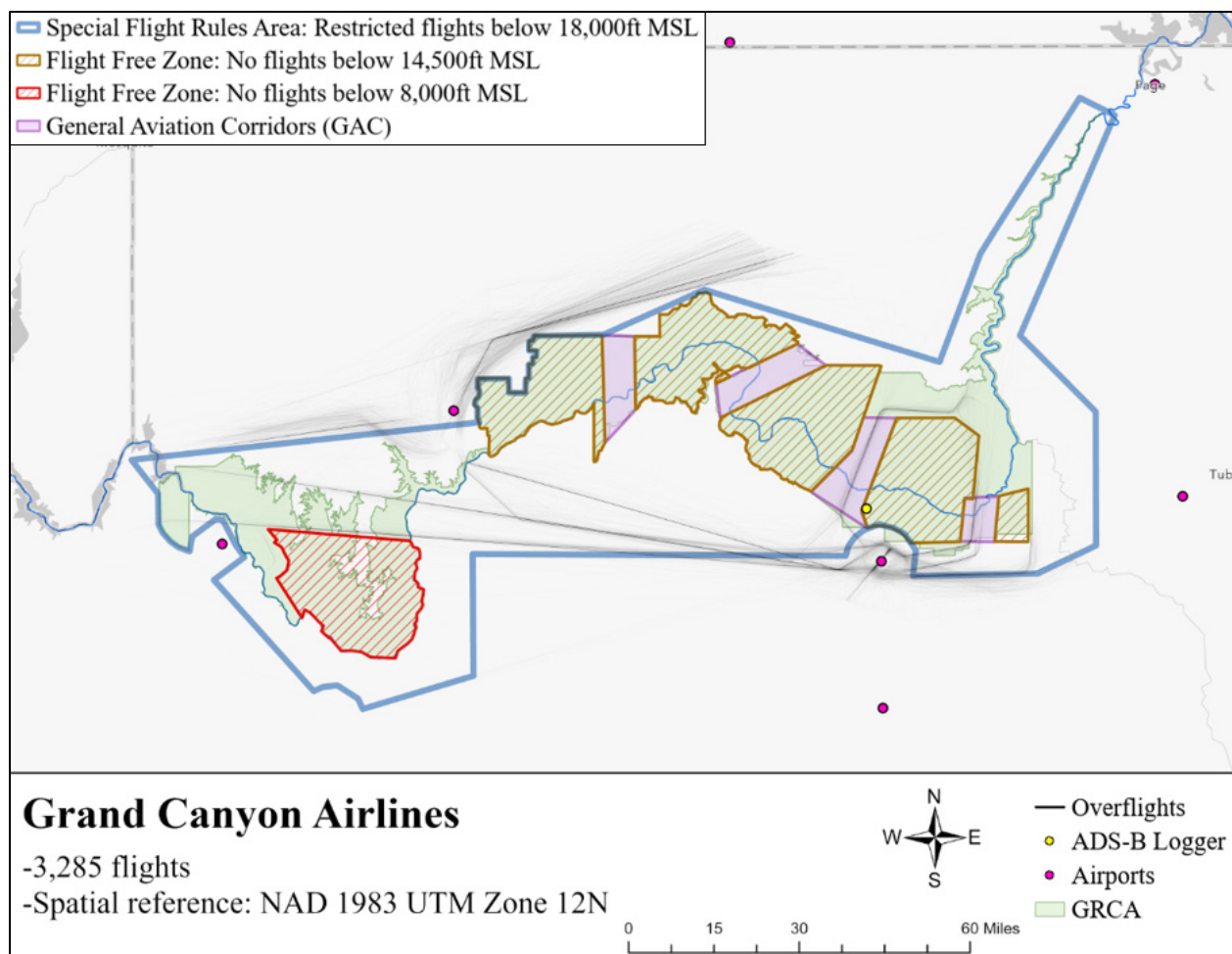


Figure 28. Overflight travel patterns for Grand Canyon Airlines.

Next, analyses were guided by park specific questions. GRCA employees reported that low-level overflights regularly occur above the South Entrance Station (36.000093, -112.121495). These low-level overflights might result from the aircraft departing or arriving at the Grand Canyon Airport which is located 4.5 miles (Euclidean distance) from the South Entrance Station. This analysis was conducted by creating a 0.5-mile buffer around the South Entrance Station and clipping Phase 1 waypoints to the buffer. Because this issue was not specific to air tours, Phase 1 waypoints were used for this analysis. These waypoints were analyzed for each year of data and were analyzed using 500 ft AGL altitude intervals (Table 8). As indicated by Table 8, there has been an increase in the number of waypoints captured in this area of the park, especially below 1,000 ft AGL.

Lastly, analysis was conducted for three tail numbers that GRCA managers identified as aircraft that are used to help in the administration of the park, such as delivering equipment. Figure 29 shows flightpaths for tail number N368PA which is GRCA's primary rotorcraft. Figure 30 shows flightpaths for tail number N838PA, which is owned by Papillon Airways and is contracted to help GRCA. Figure 31 shows N545PS, which is GRCA's fixed wing aircraft for boundary survey flights.

Table 8. Number and percentage of waypoints across AGL altitude intervals that were within 0.5-mile of South Entrance Station.

AGL altitude	2020		2021		2022	
	Number of waypoints	Percentage of waypoints	Number of waypoints	Percentage of waypoints	Number of waypoints	Percentage of waypoints
0-500 ft	13,711	66.85	34,076	77.93	46,389	84.46
501-1,000 ft	782	3.81	984	2.25	1,003	1.83
1,001-1,500 ft	178	0.87	285	0.65	166	0.30
1,501-2,000 ft	143	0.70	379	0.87	85	0.15
2,001-2,500 ft	137	0.67	777	1.78	87	0.16
2,501-3,000 ft	234	1.14	514	1.18	117	0.21
3,001-3,500 ft	277	1.35	442	1.01	209	0.38
3,501-4,000 ft	581	2.83	651	1.49	319	0.58
4,001-4,500 ft	794	3.87	1,146	2.62	221	0.40
4,501-5,000 ft	798	3.89	1,202	2.75	341	0.62
>5,000 ft	2,876	14.02	3,271	7.48	5,985	10.90

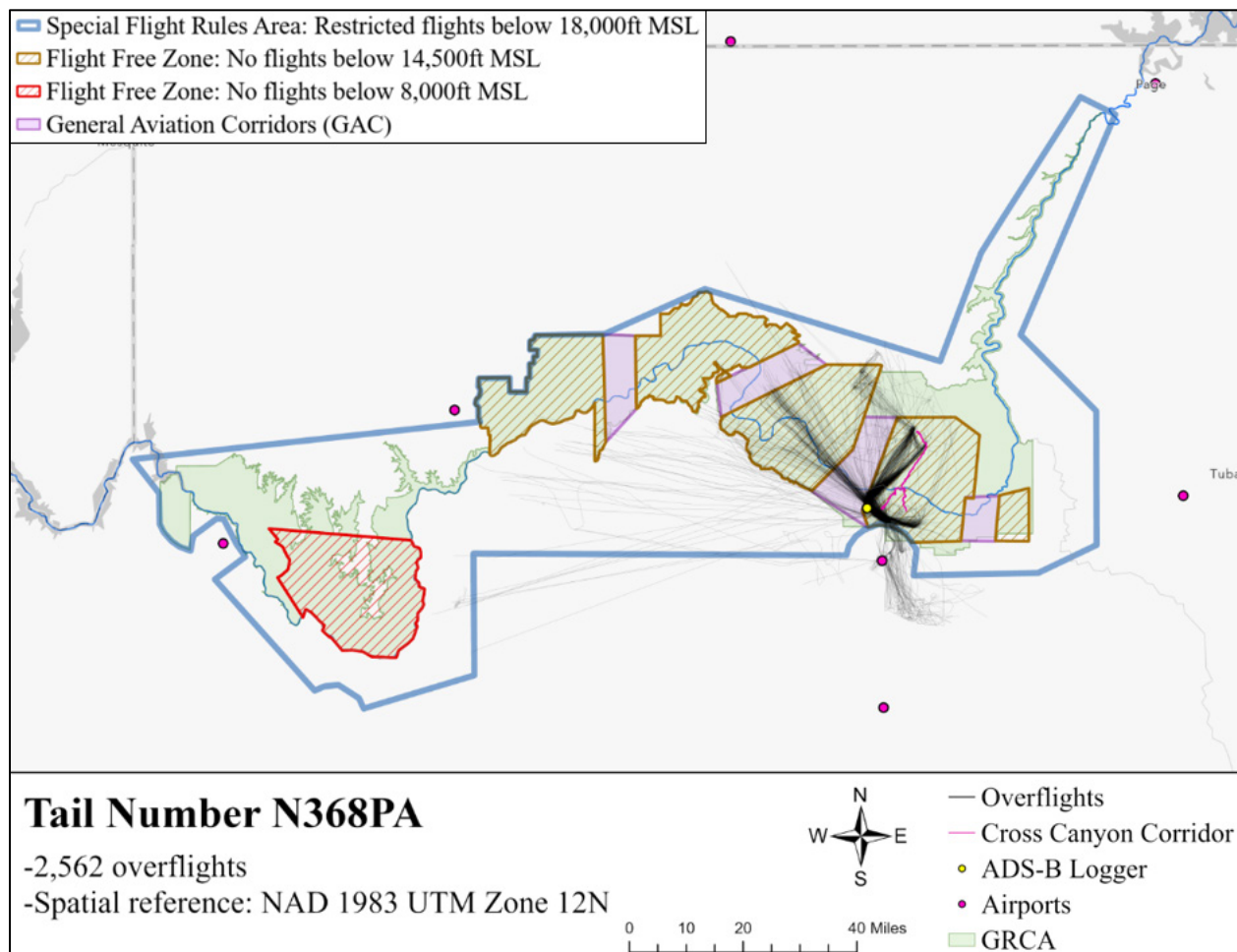


Figure 29. Overflight travel patterns for tail number N368PA.

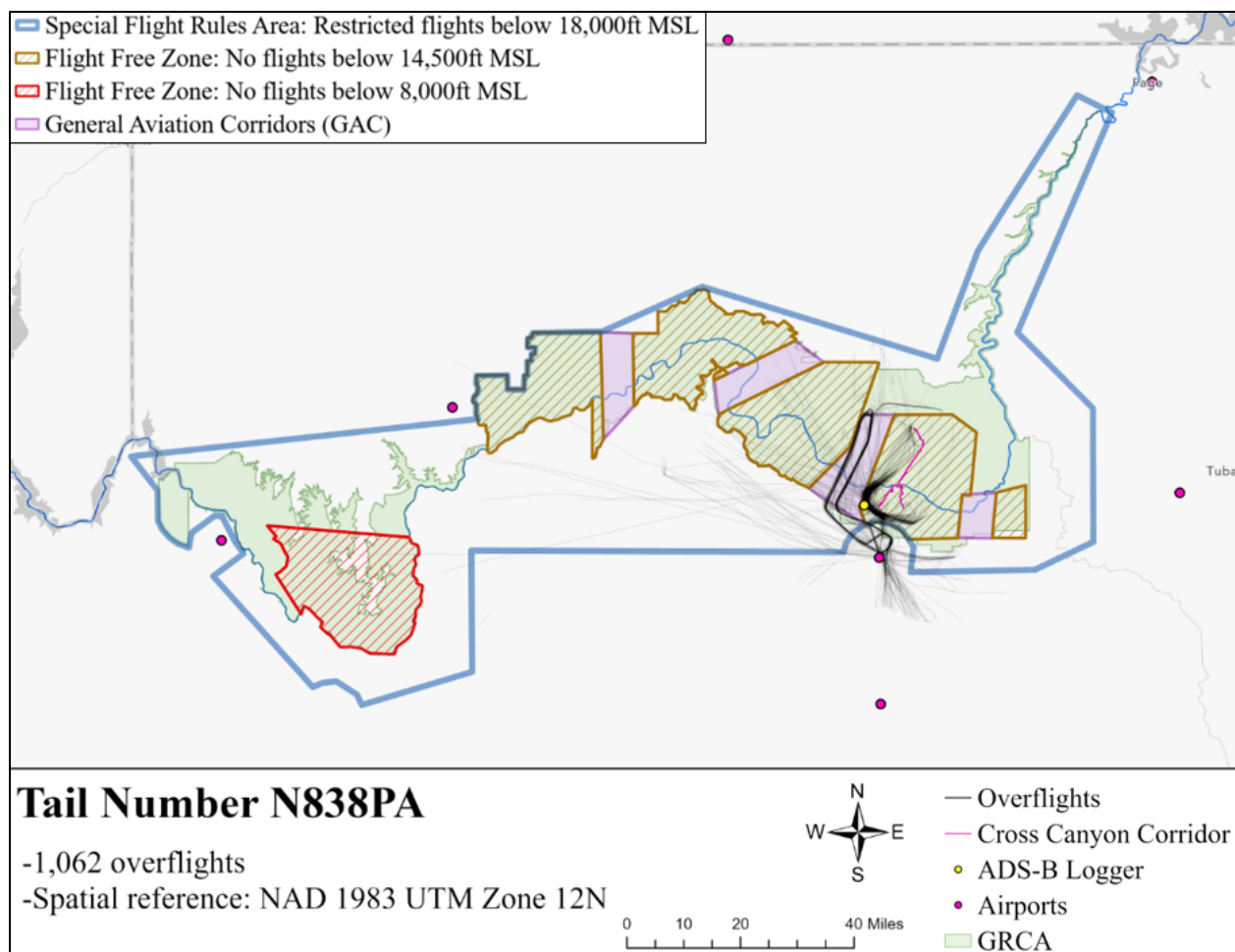


Figure 30. Overflight travel patterns for tail number N838PA.

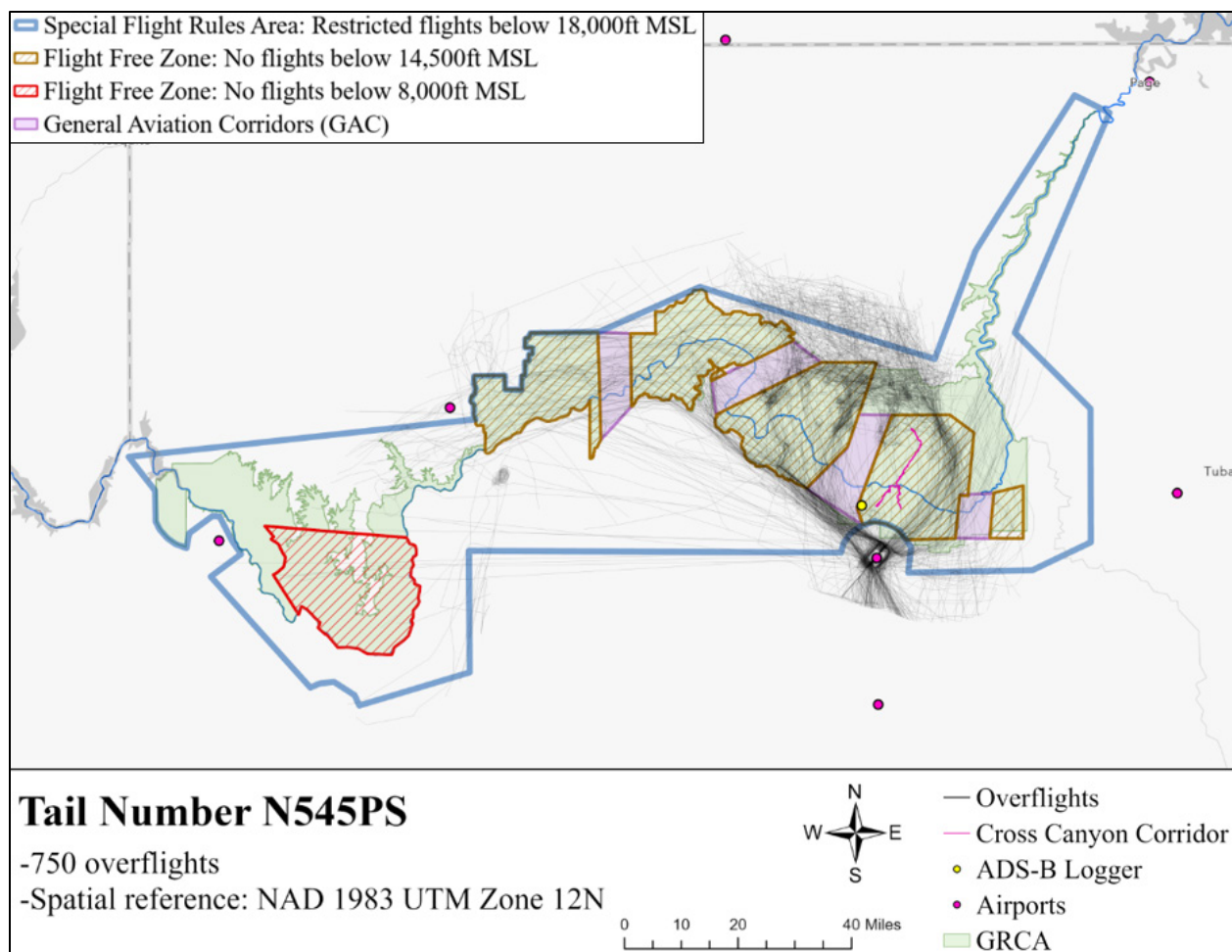


Figure 31. Overflight travel patterns for tail number N545PS.

Discussion

The purpose of this study was to explore the spatial and temporal patterns of overflights at GRCA. Flight tracking data were analyzed from February 5th, 2020 to January 9th, 2023. Analysis consisted of three phases.

The first phase focused on all overflights and showed a concentrated trend of overflights above GRCA. Visual analysis of these data suggests overflights are less concentrated above the northern perimeter of the GRCA boundary. However, this may be due to terrain shielding that blocks the data logger from receiving ADS-B signals. This phase revealed consistent route patterns over the park, including the most commonly reported air tour route, which is a loop connecting the Dragon Corridor and the Zuni Point Corridor. This loop receives concentrated flights which likely results in a consistent level of noise from aircraft (Job, 2020). Further, route patterns are very consistent with the requirements of the Special Flight Rules Area, including the use of routes, restricted areas, and corridors.

The second phase focused on low-level overflights and showed overflights fly at lower altitudes along the southeast boundary of GRCA, which is where Grand Canyon Airport (GCN) is located. This area is along the South Rim of GRCA is also known to receive the highest volume of terrestrial visitors (National Park Service, 2023). These low-level overflights are known to transmit more intense noise than higher altitude flights which could affect ground resources and visitors' experiences. Additionally, this phase of analysis showed significant flights conducted by rotorcraft and fixed wing single engine aircraft. Also, the northern and eastern stretches of the loop that connects the Dragon Corridor to the Zuni Point Corridor did not show up well in analysis, particularly for rotorcraft, which suggests terrain shielding may have prevented robust data collection for lower level flights in that area of the park. The park could consider a second ADS-B logger for the North Rim to collect additional data and fill in coverage.

The third phase attempted to focus more specifically on air tours by removing flights known to not be air tours. The dataset was cleaned of 2,191 civil patrol flights, 1,660 major airlines flights, 202,642 straight-line flights (could include private aviation, regional commercial airlines, or other types of flights), 168 flights with a flightpath less than a mile in length, and two survey flights. This left 35,279 flights. Figures 16-18 display density analysis, and reveal that density is highest along the Dragon Corridor. This analysis shows dense flights in the Dragon Corridor, which is consistent with the known air tour frequency and travel patterns. Some density, specifically very low-level flights (0-500 ft AGL; Figure 17) were found on the northern portion of the Dragon-Zuni Loop. No density was found in the Zuni Point Corridor, but this is likely due to the terrain shielding from the location of the ADS-B logger. It was found that overflight density was the highest for the altitude interval of 3,001 - 3,500 ft AGL, which is a common air tour altitude for GRCA.

Table 2, which displays number of waypoints within specific AGL altitude bands, shows that the 0 - 500 ft AGL and 501 - 1,000 ft AGL intervals received the most waypoints. Flights at altitudes lower than 1,000 ft AGL, especially lower than 500 ft AGL, are very loud. These lower level flights are located on the Dragon-Zuni Loop (Figure 17) and near the South Entrance Station (Table 8). The

South Entrance Station likely receives so many lower level flights due to the proximity to Grand Canyon Airport. The airport is located 4.5 miles (Euclidean distance) from the South Entrance Station and aircraft taking off and landing at the airport might be flying at low altitudes during ascent and descent. However, the lower level flights near the South Entrance Stations did not have the highest density of flights, rather, the Dragon-Zuni Loop held the most density. This is likely due to the concentration of flights while on air tours, and a more general dispersion of flights near the South Entrance Station. Specifically focusing on the density figures, density was found across numerous altitude bands with the highest density in the 3,001 – 3,500 ft AGL range rather than the lower levels (0 – 500 ft AGL and 501 – 1,000 ft AGL altitude intervals) where to most points were found. Because these two lowest altitude intervals did not have the highest density of flights, it suggests that aircraft at these altitude intervals are flying with more variation in their flight patterns than at the altitude interval with the highest density of flights (3,001 – 3,500 ft AGL). Density analysis for the 3,001 – 3,500 ft AGL altitude interval shows dense flights in the Dragon Corridor which is a narrow corridor that likely prevents flight pattern variations.

Figures 26-28 display travel patterns for the three operators who conducted the most flights. These operators and their number of flights are: Papillon Airways (18,694 flights), Maverick Helicopters (15,079 flights), and Grand Canyon Airlines (3,285 flights). The flight patterns of these operators show that they regularly fly a loop formation that connects the Dragon Corridor and the Zuni Point Corridor.

Table 5 shows percentage of flights are similar across days of the week with the lowest percentage of flights occurring on Tuesdays (12.90%) and the highest percentage of flights occurring on Saturdays (15.50%) and Sundays (15.10%). Table 6 displays percentage of overflights across hours of the day, revealing that a significant number of flights begin at 9:00am and continue until 3:00pm. Table 6 shows that early morning (6:00am-8:00am) and evening (6:00pm-8:00pm) have the lowest level of air tours. Finally, figures 29 and 30 focus on aircraft that always (N368PA) or sometimes (N838PA) are used for park operations. These aircraft seem to account for most of the flights in the SFRA flight free zone directly north of the Grand Canyon Airport.

Much of the data from this study are located over the southeast portions of the park. This is likely due to the location of the ADS-B logger. Therefore, it is not clear if these data represent a comprehensive understanding of overflights over the entire park, especially the western portion of the park.

In conclusion, this study produced results to further understand overflights at GRCA. This information can be used for planning and management purposes. This study serves as a resource for future research that intends to use more advanced analytics.

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NPS 113/189868, July 2023

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1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525