COCA CULTIVATION IN PERU: A GEOSPATIAL INTELLIGENCE COLLECTION PLAN

by
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Contents

Introduction

The United States takes a particular interest in nations that produce illegal narcotics; the drug trade often finances terrorist organizations, is tied to crime or violence, influences international affairs, or is intertwined with government corruption. For decades, especially amongst Central and South American countries, the widespread production, distribution, and consumption of illegal drugs has destroyed communities, dominated the political sphere, controlled sectors of the global economy, damaged natural environments, and influenced history.[1,2,3]

"The greatest enemy of peacebuilding in Colombia is drug trafficking," Colombian President Ivan Duque stated during a presentation at the United Nations Office on Drugs and Crime in June of 2021.[4] Colombian government officials claim that cocaine production in particular has claimed over 200,000 lives and left millions displaced in the past 50+ years.[5,6] Colombia remains one of the world's largest cocaine producers in the world, accountable for 70% of the global supply in 2017 and 90% of samples tested in the United States in 2018.[7,8]

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[1] Clerici, N., et al., "Deforestation in Colombian protected areas increased during post-conflict periods," *Scientific Reports* 10, 4971, 18 March 2020. https://doi.org/10.1038/s41598-020-61861-y
[2] Mrkonjic, Elma, "41 Surprising War on Drugs Statistics [The 2021 Edition]," *The High Court*, 2021, https://the highcourt.co/war-on-drugs-statistics/
[3] U.S. Department of Justice and Drug Enforcement Administration, "2020 Drug Enforcement Administration NDTA: National Drug Threat Assessment," *Cocaine*, 29-36 (2021): https://www.dea.gov/sites/default/files/2021-02/DIR-008-21%202020%20National%20Drug%20Threat%20Assessment_WEB.pdf
[4] Reuters, "Colombia cut coca crop area in 2020 but cocaine output rose – UNODC," *Reuters, Americas*, 9 June 2021, https://www.reuters.com/world/americas/colombia-cut-coca-crop-area-2020-cocaine-output-rose-unodc-2021-06-09/
[5] Ibid.
[6] Grupo de Memoria Histórica, "¡Basta Ya! Colombia: Memorias de Guerra y Dignidad," Informe General, Centro Nacional de Memoria Histórica, 2015, https://web.archive.org/web/20151211005217/http://www.centrodememoria historica.gov.co/descargas/informes2013/bastaYa/bastaya-colombia-memorias-de-guerra-y-dignidad-2015.pdf
[7] teleSUR, "Colombia Produced More Than 70% of World Cocaine in 2017: UN," *Colombia*, 26 June 2019, https:// www.telesurenglish.net/news/Colombia-Produced-More-Than-70-of-World-Cocaine-in-2017-UN-20190626-0011.html
[8] Burnett, Lynn Barkley, "Cocaine Toxicity," *Drugs and Diseases, Emergency Medicine*, 31 December 2020, https://emedicine.medscape.com/article/813959-overview

To mitigate Colombia's participation in the global narcotics supply chain, the Colombian government has announced the decriminalization and legalization of marijuana in an effort to diminish the illegal use of cocaine.[9] Additionally, Colombian officials have enacted growing limitations and controversial aerial eradication tactics to reduce coca cultivation, a plant whose leaves serve as the primary source of cocaine.[10,11] Although Colombia's changes in legislation and initiative to cut the number of coca plants in the region may have resulted in some positive domestic impact, the ever-rising demand for cocaine must either remain unanswered or be supplied by other countries. The impact of Colombia's policy on neighboring countries that also cultivate coca (like Bolivia or Peru) is yet to be fully understood.

Most literature that analyzes illicit agriculture of coca plants is outdated, or considers general relationships across large regions in Central and South America or solely domestic trends; a case study that compares two specific countries may provide insight on how narcotics-related legislation can have short-term or regional impact.[12,13,14,15] This paper – a geospatial intelligence (GEOINT) collection plan – serves as a foundation to understanding the relationship

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[9] Mejia, Daniel, "Plan Colombia: An Analysis of Effectiveness and Costs," *Foreign Policy,* Center for 21st Century Security & Intelligence, Latin America Initiative, Universidad de los Andes (2016). https://www.brookings.edu/wp-content/uploads/2016/07/mejia-colombia-final-2.pdf

[10] Karáth, Kata, "Pandemic upends Colombia's controversial drug war plan to resume aerial spraying," *Science, Latin America,* 11 June 2020, https://www.sciencemag.org/news/2020/06/pandemic-upends-colombia-s-controversial-drug-war-plan-resume-aerial-spraying

[11] U.S. Department of Justice and Drug Enforcement Administration, "Coca Cultivation and Cocaine Processing: An Overview," Office of Intelligence, February 1991, https://www.ojp.gov/pdffiles1/Digitization/132907NCJRS.pdf

[12] United Nations Office on Drugs and Crime, "Coca Cultivation in the Andean Region: A Survey of Bolivia, Colombia, and Peru," June 2006, https://www.unodc.org/pdf/andean/Andean_full_report.pdf

[13] Sarita, Kendall, "South American Cocaine Production," *Cultural Survival,* December 1985. https://www.culturalsurvival.org/publications/cultural-survival-quarterly/south-american-cocaine-production

[14] United Nations Office on Drugs and Crime, "UNODC Annual Report 2018," 2018, https://www.unodc.org/unodc/en/about-unodc/annual-report.html

[15] United Nations Office on Drugs and Crime, UNODC ICMP, DEVIDA Comision Nacional para el Desarrollo y Vida Sin Drogas, "Peru Monitoreo de Cultivos de Coca," *UNODC and illicit crop monitoring,* UNODC Research, 2003-2018. https://www.unodc.org/unodc/en/crop-monitoring/index.html?year=2021

between Colombia's marijuana-related legislation changes/coca plant reduction initiatives and current coca cultivation in Peru and if such changes can be detected and measured.

This report will include an overview of the cultivation cycle of coca plants, the conditions for geospatial collection (e.g., cloud cover, precipitation, elevation, drone laws) in four of the most prominent Peruvian coca cultivation areas, the types of platforms, sensors, images, and collection necessary to characterize and quantify Peruvian cultivation, and the relative cost of the project. The data may provide indications about how the Colombian reduction of coca cultivation and legalization of marijuana has influenced Peruvian coca cultivation; further, the development and deployment of a geospatial intelligence collection plan will lay the groundwork for future analysis of coca cultivation in other countries that contribute to the international supply and distribution of cocaine, like Bolivia.[16]

[16] Mallette, Jennifer, et al., "Geographically Sourcing Cocaine's Origin – Delineation of the Nineteen Major Coca Growing Regions in South America," *Scientific Reports* 6, no. 23520 (2016): 1-10. https://www.nature.com/articles/srep23520

Collection Considerations and Coca Cultivation Cycle

In Peru, coca plants are grown in the eastern high-humidity slopes of the Andes Mountains beneath the cover of jungle canopies.[17] Ideal growing plateaus with suitable soil and sunlight can reach altitudes of nearly 2,000 meters (~6,560 feet), though many exist in the lowland plains.[18] According to the United Nations Office on Drugs and Crime's most recent records on growing locations in Peru, one of the highest concentration areas of coca cultivation exists near the villages of Loromayo, Lechemayo, Puerto Manoa, and Challhuamayo (Figure 1, 2).[19] This region showed a 226% increase of cultivated areas with productive coca from 2016 to 2017, and as of 2018, was not subject to intervention by Peru's Special Project for the Control and Reduction of Illegal Crops in Alto Huallaga.[20]

Figure 1. *Area of interest.*
Courtesy of citypopulation.de, Esri, UNODC, mapcarta.com, Google Maps, Earthstar Geographics, OpenStreetMap

[17] Sarita, Kendall, "South American Cocaine Production," *Cultural Survival*, December 1985. https://www.culturalsurvival.org/publications/cultural-survival-quarterly/south-american-cocaine-production
[18] Ibid.
[19] United Nations Office on Drugs and Crime, UNODC ICMP, DEVIDA Comision Nacional para el Desarrollo y Vida Sin Drogas, "Peru Monitoreo de Cultivos de Coca," *UNODC and illicit crop monitoring,* UNODC Research, 2003-2018. https://www.unodc.org/unodc/en/crop-monitoring/index.html?year=2021
[20] Ibid.

All four locations are in the Ayapata district in the Carabaya province of Peru's Puno region.[21] Along the Inambari River and its tributaries, these lowly-populated villages vary in both altitude and slope exposure, making the collection of spaceborne or airborne imagery and remote sensing a challenge (Figure 2).

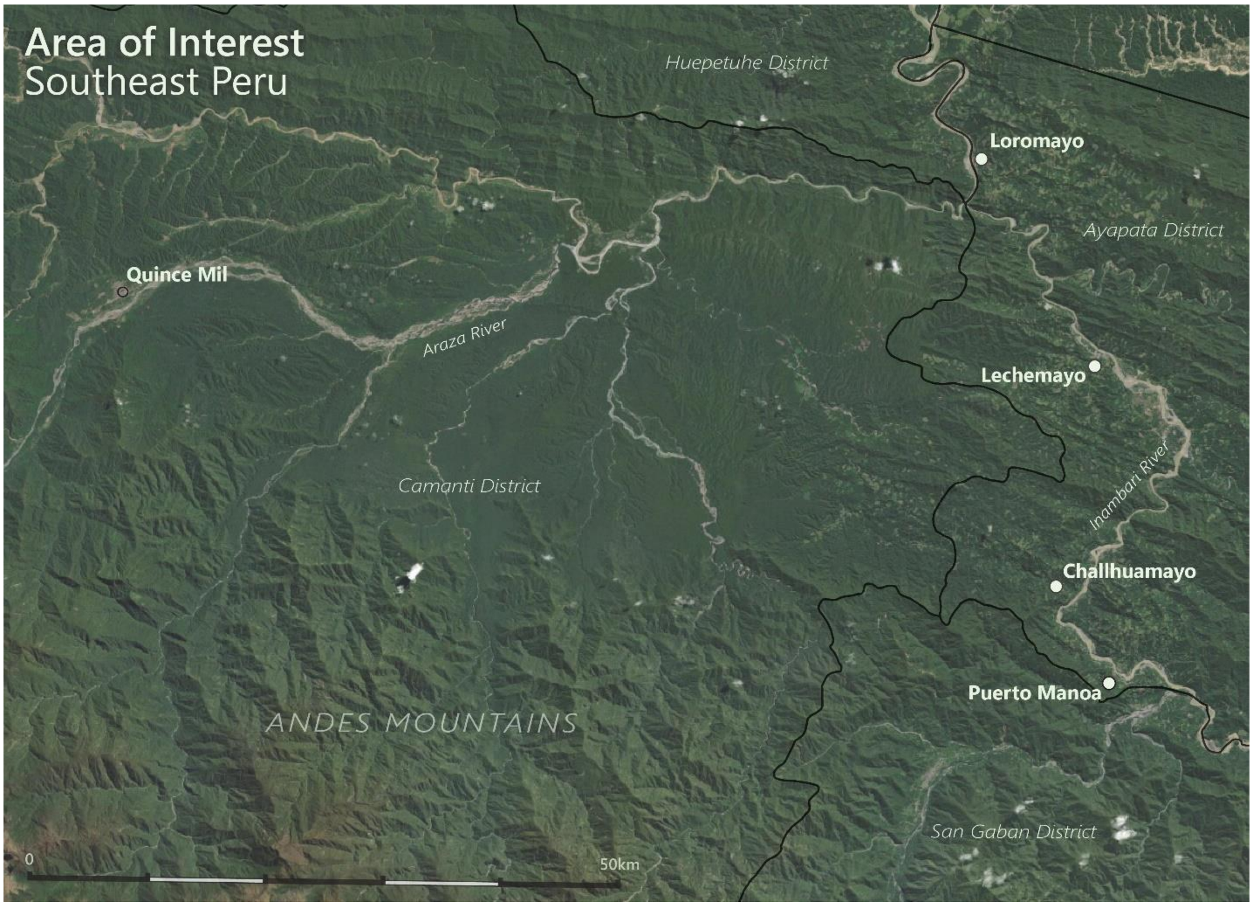

Figure 2. *Loromayo, Lechemayo, Challhuamayo, and Puerto Manoa (the area of interest) in relationship to nearby Quince Mil, used for climate estimations.*
Courtesy of DIVA-GIS, citypopulation.de, Esri, UNODC, mapcarta.com, OpenStreetMap, Earthstar Geographics

Peru's southeastern side of the Andean region typically experiences a rainy season from November to April, and constant snowfall makes agriculture unsustainable at altitudes above

[21] United Nations Office on Drugs and Crime, UNODC ICMP, DEVIDA Comision Nacional para el Desarrollo y Vida Sin Drogas, "Peru Monitoreo de Cultivos de Coca," *UNODC and illicit crop monitoring,* UNODC Research, 2003-2018. https://www.unodc.org/unodc/en/crop-monitoring/index.html?year=2021

5,000 meters (~16,400 feet).[22,23] In general, coca cultivation in Peru's most concentrated growing areas is most likely to occur at elevations between 300 and 1,000 meters (~985-3,280 feet).[24,25] Based on averages from the neighboring town of Quince Mil, the cloudy season occurs between 1 October and 1 May; both cloud cover and precipitation peak between mid-January to early February, with a 93% chance of the day being overcast and a 62% chance of rain (Figure 2, Figure 3).[26] Quince Mil is less than 40 kilometers from the area of interest and lies at an altitude 100-200 meters higher depending on which village it is compared to.

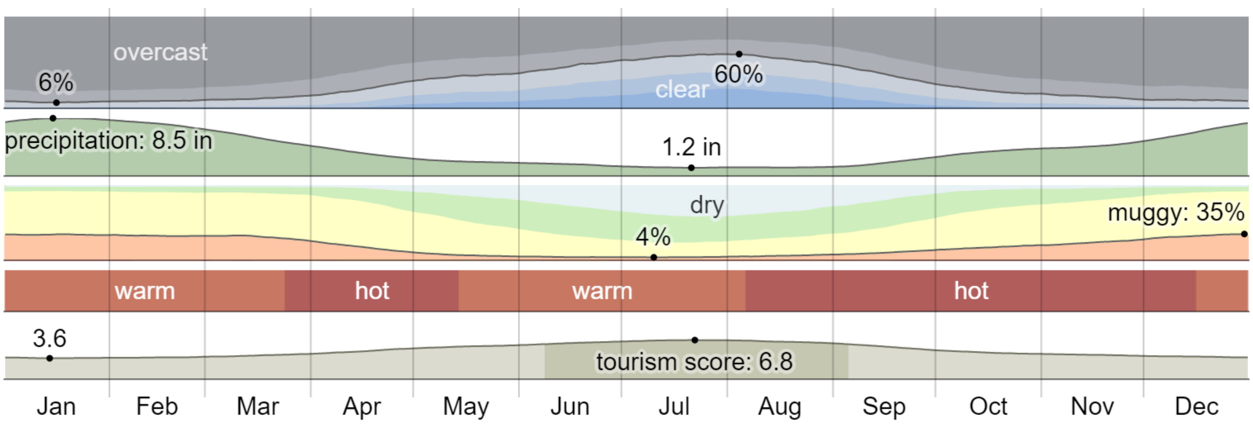

Figure 3. *Climate summary of nearby Quince Mil*. *© WeatherSpark.com*

Planting season should also be considered in the context of climatic phenomena like El Niño or La Niña, both of which significantly influence cultivation patterns in South America on irregular intervals. The oscillation between warmer-than-average and colder-than-average phases typically impacts Peru every 5-7 years, leading to substantial changes in wind,

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[22] Weather & Climate, "Climate and Average Weather in Peru," Climate in Peru, n.d., https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine-in-Peru
[23] Climates to Travel, "Climate – Peru," *World Climate Guide*, n.d., https://www.climatestotravel.com/climate/peru#andes
[24] Jarvis Andy, et al., "Hole-filled seamless SRTM data," V4, International Centre for Tropical Agriculture (CIAT), 2008, https://srtm.csi.cgiar.org/
[25] U.S. Department of Justice and Drug Enforcement Administration, "Coca Cultivation and Cocaine Processing: An Overview," Office of Intelligence, February 1991, https://www.ojp.gov/pdffiles1/Digitization/132907NCJRS.pdf
[26] Weather Spark, "Climate and Average Weather Year Round in Quince Mil," accessed 16 Feb 2022, https://weatherspark.com/y/26627/Average-Weather-in-Quince-Mil-Peru-Year-Round

precipitation, and temperature.[27] Its occurrence may alter coca planting times and should be monitored accordingly.[28]

The coca planting season in the Andean regions of Colombia, Peru, and Bolivia typically occurs between December and March depending on the specific region and climate, with the most abundant harvest season occurring between late February and early April about 1-2 years into its maturation cycle.[29] Though there are additional harvesting seasons in June/July and October/November, the March harvest is sometimes responsible for approximately half of the total yearly harvest in South America.[30] Naturally-occurring coca plants can grow to be more than 9 meters (30 feet) tall, but cultivated coca plants are often pruned to ~1-2 meters (3-6 feet) to stimulate growth and increase their yield.[31] After removal, leaves are transported and laid out to dry in the sunlight or under heat lamps for several hours.

Beyond the production of cocaine, it is important to mention the cultural significance of coca plants; outlawing and eradicating its cultivation is controversial among legal users and conservationists. Coca leaves have been used holistically to alleviate hunger and altitude sickness for thousands of years, can be chewed or brewed in teas, and are even exported in small quantities legally.[32]

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[27] NOAA, "El Niño & La Niña (El Niño-Southern Oscillation)," *What is ENSO?* 14 October 2021, https://www.climate.gov/enso
[28] Climate Prediction Center/NCEP/NWS and the International Research Institute for Climate and Society, "El Niño/Southern Oscillation (ENSO) Diagnostic Discussion," NOAA, 10 March 2022. https://www.cpc.ncep.noaa .gov/products/analysis_monitoring/enso_advisory/ensodisc.shtml
[29] U.S. Department of Justice and Drug Enforcement Administration, "Coca Cultivation and Cocaine Processing: An Overview," Office of Intelligence, February 1991, https://www.ojp.gov/pdffiles1/Digitization/132907NCJRS.pdf
[30] Ibid.
[31] Ibid.
[32] Sarita, Kendall, "South American Cocaine Production," *Cultural Survival*, December 1985. https://www.cultural survival.org/publications/cultural-survival-quarterly/south-american-cocaine-production

Colombia is currently the only state to have practiced aerial spray eradication of some coca plants with herbicides, which was halted solely in the wake of the COVID-19 pandemic.[33] Glyphosate, the primary chemical used in aerial eradication, can damage sensitive soil and water systems and is often sprayed across inhabited areas, leading to life-threatening side-effects.[34] Though more environmentally sustainable, manual eradication efforts are becoming increasingly dangerous as terrorists and cultivators place mines and improvised explosive devices to target eradicators and protect crops.[35] Civilian manual eradicators, police officers, and members of the military were subject to attacks, IEDs, mines, and sniper fire that led to over 30 fatalities and nearly 150 injuries amongst eradication personnel in 2010 alone.[36]

[33] Karáth, Kata, "Pandemic upends Colombia's controversial drug war plan to resume aerial spraying," *Science, Latin America*, 11 June 2020, https://www.sciencemag.org/news/2020/06/pandemic-upends-colombia-s-controversial-drug-war-plan-resume-aerial-spraying
[34] van Royen, Marjon, "Driven By Mad Itch," NRC Handelsblad, 28 December 2000, https://marjonvanroyen.nl/index.php?option=com_content&view=article&id=525&Itemid=46.
[35] Office of National Drug Control Policy, "Coca In The Andes," Obama Administration Archives, n.d., https://obamawhitehouse.archives.gov/ondcp/targeting-cocaine-at-the-source
[36] Ibid.

Required Platforms, Sensors, and Imagery

Platforms

To monitor coca cultivation near Peru's Southeast Andes, using an aerial collection platform would be most flexible and cost-efficient. Airborne platforms can get far closer to target areas and provide dramatically better resolution or sequential coverage than spaceborne collectors; they are also often capable of flying below cloud cover.[37] Airborne sensors can be easily modified and adjusted between collection pursuits and are unlikely to be subject to robust counter-air weaponry from terrorist organizations or protective cultivators operating beneath the jungle canopies (though the possibility still exists, especially as coca cultivation advances in Peru). However, given the Puno region's proximity to the Andes and characteristic rains during the wet season, manned or unmanned aircraft may be susceptible to significant turbulence and weather-related obstructions that may degrade the quality or likelihood of quality GEOINT collection.[38] It is important to plan collection in the context of rough air from oscillating wind patterns associated with mountain ranges, as well as heavy precipitation and cloud cover typical for the growing season.[39,40]

Aircraft and drone laws are lenient in Peru, only limiting flight over large crowds, historical sites like Machu Picchu, or military and government facilities.[41] As Loromayo, Lechemayo, Puerto Manoa, and Challhuamayo are all small, rural, uncontested villages with

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[37] Clark, Robert, *Intelligence Collection*, Collection Platforms, 187-209 (CQ Press, 2014). ISBN 978-1-4522-7185-9
[38] Ibid.
[39] Donahue, Michelle, "What is turbulence – and how can you calm down about it?" *National Geographic, Travel,* 22 February 2019, https://www.nationalgeographic.com/travel/article/what-is-turbulence-explained
[40] Weather Spark, "Climate and Average Weather Year Round in Quince Mil," accessed 16 Feb 2022, https://weatherspark.com/y/26627/Average-Weather-in-Quince-Mil-Peru-Year-Round
[41] UAV Systems International, "Peru Drone Laws," 2019, https://uavsystemsinternational.com/pages/peru-drone-laws

populations of less than 2,000, legal complications would be minimal even if using commercial drones for imagery collection.[42]

The level of collection urgency has a significant influence on the choice of a manned or unmanned aerial vehicle, especially when monitoring illicit agriculture. Collection revolves around the timing of a growing season, and in this case, a historically cloudy, rainy, and mountainous growing environment. If intelligence collection is time-sensitive, choosing to fly a piloted airplane is a traditional, reliable, fast-for-planning option, but may not be as affordable as unmanned aircraft.[43]

Unmanned systems typically have lower costs of acquisition, smaller recurring costs per flight hour, fewer training costs, and, of course, do not risk priceless pilot life (and their rigorous and expensive training to conduct missions such as these).[44,45] Even though most violence surrounding the protection and concealment of illicit crops is directed at law enforcement, military, and other manual eradicators – and the unlikelihood that regional cultivators will sport technology complex enough to counter or destroy aircraft of any kind – the potential for hostility or countermeasure still exists, thus making UAVs a safer choice.[46] Additionally, drones eliminate pilot salaries, pilot insurance or legal fees if the pilot is injured or killed, and potentially, several types of hazardous duty incentive pay (HDIP).[47]

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[42] Chopra, Anil, "Manned vs Unmanned," SP's Aviation, Aug 2013, https://www.sps-aviation.com/story/?id=1278
[43] Shrestha, Rakesh, et al., "A Survey on Operation Concept, Advancements, and Challenging Issues of Urban Air Traffic Management," Frontiers in Future Transportation, Transportation Systems Modeling, 26 April 2021, https://www.frontiersin.org/articles/10.3389/ffutr.2021.626935/full
[44] Congressional Budget Office, "Usage Patterns and Costs of Unmanned Aerial Systems," Nonpartisan Analysis for the U.S. Congress, June 2021, https://www.cbo.gov/publication/57260
[45] Dörtbudak, Mehmet Fevzi, "Unmanned Aerial Vehicles (UAVs): a new tool in counterterrorism operations?" *Proceedings* 9456, Sensors, and Command, Control, Communications, and Intelligence (C3I), Technologies for Homeland Security, Defense, and Law Enforcement XIV; 94560H, 23 May 2015, https://doi.org/10.1117/12.2085373
[46] Office of National Drug Control Policy, "Coca In The Andes," Obama Administration Archives, n.d., https://obamawhitehouse.archives.gov/ondcp/targeting-cocaine-at-the-source
[47] U.S. Department of Defense, "Hazardous Duty Incentive Pay (HDIP)," Military Compensation, Pay, Special and Incentive Pays, accessed 7 February 2022, https://militarypay.defense.gov/Pay/Special-and-Incentive-Pays/HDIP/

Four airfields in southeast Peru have the potential to support geospatial intelligence collection in Peru's Ayapata District: Alejandro Velasco Astete Cusco, Padre Aldamiz International, Inca Manco Capac International, and the nearest military airport, La Joya Air Base (Figure 5).[48,49,50] Alejandro Velasco Astete and Padre Aldamiz International are closest to the centroid of the area of interest, 175 kilometers (109 miles) and 143 kilometers (89 miles) away respectively; however, the elevation of Alejandro Velasco Astete is greater than 3,000 meters (~9,850 feet) while Padre Aldamiz is 210 meters (~690 feet). The elevation of Challhuamayo, Loromayo, Lechemayo, and Puerto Manoa is between 360-460 meters (~1180-1510 feet). Thus, Padre Aldamiz International is the best airfield due to its close proximity and limited altitude change.

Aircraft will need sufficient range to 1) depart from Padre Aldamiz International and fly +/- 150 kilometers (93 miles) to the area of interest, 2) sample an area of approximately 730 km^2 (280 mi^2) and 3) fly +/- 150 kilometers (93 miles) back to the airfield. To limit interference with image clarity from the significant and near-constant cloud cover in the region, aircraft must be capable of flying below the cloud base. The cloud base can be estimated using the following equation, where temperatures are in Celsius and the cloud base is in feet:[51,52]

$$cloud\ base = \frac{ground\ temperature - dew\ point}{2.5} \times 1000$$

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[48] Great Circle Mapper, "Peru: Airport Info," accessed 4 Nov 2021, http://www.gcmap.com/search?Q=Peru&EC=A
[49] Mapcarta, "Base Aérea La Joya," Peru, South America, accessed 5 Nov 2021, https://mapcarta.com/W231759499
[50] OurAirports, "Peru," accessed 2 April 2022, https://ourairports.com/countries/PE/
[51] Drone Pilot Ground School, "How can I calculate the cloud base to ensure I'm complying with the 500 ft. rule?" Drone Rules and FAA Regulations, accessed 17 Feb 2021, https://www.dronepilotgroundschool.com/kb/how-can-i-calculate-the-cloud-base-to-ensure-im-complying-with-the-500-ft-rule/
[52] Colgate, David, "How to estimate cloud bases and heights," Airbourne Aviation, Tips and Info, 18 May 2018, https://www.flymac.co.uk/how-to-estimate-cloud-bases-and-heights/

In February where crops are nearing their typical age of harvest, the average temperature of nearby Quince Mil is 25 degrees Celsius (77°F); the relative humidity is approximately 34%, yielding a dew point of about 8 degrees Celsius (46°F).[53,54] Using the equation for cloud cover, the cloud base lies near 2,073 meters (6,800 feet) above the ground.

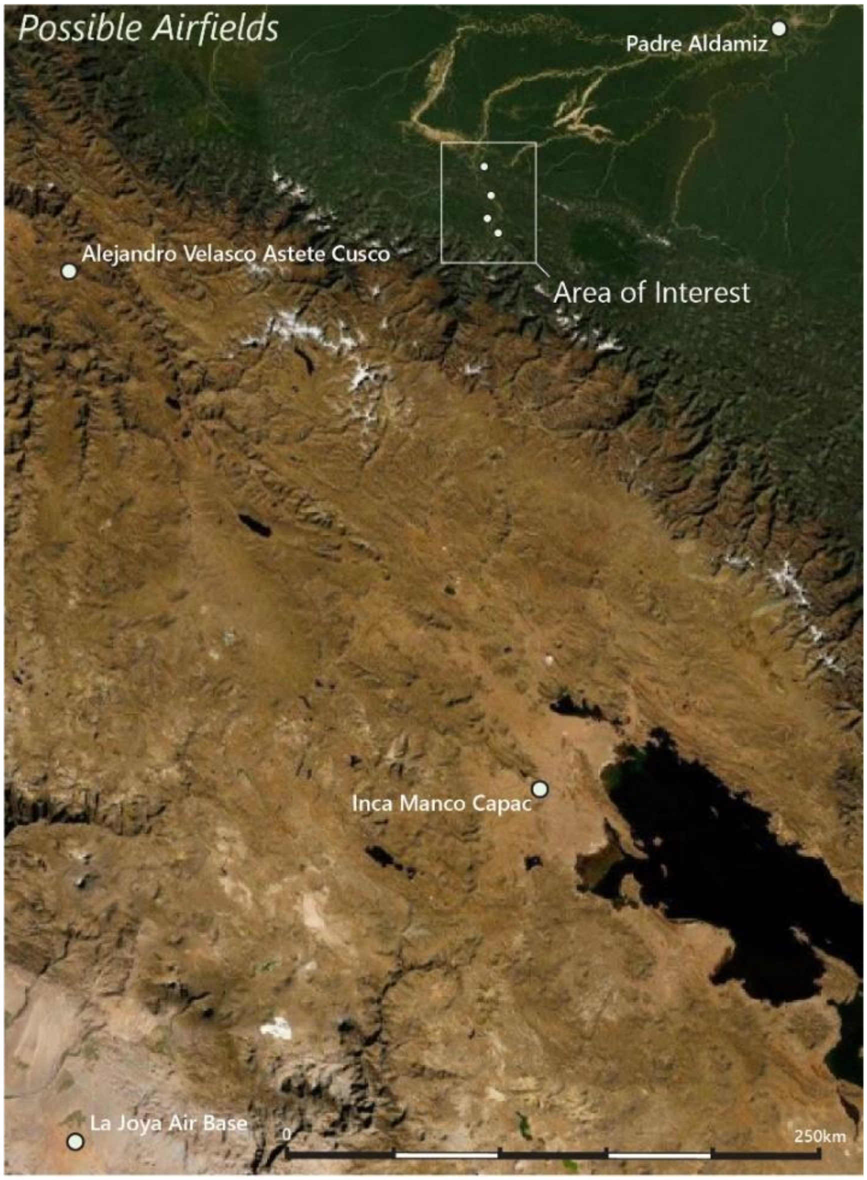

Figure 4. *Possible airfields and their proximity to the area of interest.*
Courtesy of DIVA-GIS, citypopulation.de, Esri, UNODC, mapcarta.com, OpenStreetMap

[53] U.S. Department of Justice and Drug Enforcement Administration, "Coca Cultivation and Cocaine Processing: An Overview," Office of Intelligence, February 1991, https://www.ojp.gov/pdffiles1/Digitization/132907NCJRS.pdf
[54] Weather Spark, "Climate and Average Weather Year Round in Quince Mil," accessed 16 Feb 2022, https://weatherspark.com/y/26627/Average-Weather-in-Quince-Mil-Peru-Year-Round

It is recommended that drones fly no less than 152 meters (500 feet) below the cloud base, indicating the necessity of a Group 2, low-altitude, long-endurance (LALE) UAV for collection.[55,56,57,58] Due to the ~150km distance between the closest airfield and the centroid of the area of interest, an unmanned aerial system that also provides significant range capabilities – such as Boeing's ScanEagle – is most appropriate for the mission and more cost-effective than its manned counterparts.[59,60,61] The ScanEagle supports payloads of up to 5 kilograms, is less than 2 meters in length with a ~10m wingspan, and is compatible with a variety of different sensors.[62] Its ceiling of 5,950 meters (19,500 feet), cruise speed of 50-60 knots (approximately 92-111 kilometers/hour or 57-69 miles/hour), and endurance of 18 hours provides a high level of reliability and versatility for an area of such variable altitude, cloud cover, and precipitation patterns.[63]

Sensors and Imagery

First, the collection of baseline panchromatic imagery (PAN) across the entire area of interest is necessary to identify sample areas to revisit with additional sensors.[64] PAN imagers

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[55] Drone Pilot Ground School, "How can I calculate the cloud base to ensure I'm complying with the 500 ft. rule?" Drone Rules and FAA Regulations, accessed 17 Feb 2021, https://www.dronepilotgroundschool.com/kb/how-can-i-calculate-the-cloud-base-to-ensure-im-complying-with-the-500-ft-rule/

[56] Rupprecht, Jonathan, "Section 107.51 Operating limitations for small unmanned aircraft," *Drone Law and Drone Attorney Assistance*, 5 March 2021, https://jrupprechtlaw.com/section-107-51-operating-limitations-for-small-unmanned-aircraft/#:~:text=Base%20Altitude%20Calculator-,Instructions,stay%20500%20feet%20below%20clouds

[57] RADA Technologies, "UAV Types and Detection," *RADA USA*, 5 October 2020, https://radausa.com/blog/uav-types

[58] UAS Task Force, Airspace Integration Integrated Product Team (U.S. Department of Defense), "Unmanned Aircraft System Airspace Integration Plan," Version 2.0, March 2011, https://web.archive.org/web/20160121155841/http://www.acq.osd.mil/sts/docs/DoD_UAS_Airspace_Integ_Plan_v2_(signed).pdf

[59] Naval Technology, "ScanEagle – Mini-UAV (Unmanned Aerial Vehicle)," 22 August 2007, https://www.naval-technology.com/projects/scaneagle-uav/

[60] Insitu, "ScanEagle," accessed 18 Feb 2022, https://www.insitu.com/products/scaneagle

[61] Boeing, "ScanEagle," accessed 18 Feb 2022, https://www.boeing.com/defense/autonomous-systems/scaneagle/index.page#/video/scaneagle-launch-and-recovery

[62] Ibid.

[63] Ibid.

[64] Clark, Robert, *Intelligence Collection*, Radiometric and Spectral Imaging, 245-275 (CQ Press, 2014). ISBN 978-1-4522-7185-9

create pictures similar to black-and-white aerial photographs by capturing the visible part of the electromagnetic spectrum in addition to part of the infrared spectrum.[65] Panchromatic imagers can be used to detect crop locations at resolutions of 1.5 meters or higher; given that coca crops are pruned to remain between 1-2 meters in height, an electro-optical sensor capable of capturing panchromatic imagery will allow imagery analysts to identify sample areas.[66,67,68] Additionally, cultivation areas may also be near other indicators of illicit agriculture, such as transport vehicles, makeshift buildings or camps, or 55-gallon drums often attributed to drug processing and narcotics development that are not characteristic to the deep, remote Peruvian jungle.[69]

After all sample areas are identified, returning to collect multispectral imagery (MSI) would then help assess the crop vigor and the scope of the sites' operations.[70,71,72] Multispectral imagery makes it possible to differentiate between materials on the ground by separating spectrally the signatures of manmade and natural features; it also allows analysts to draw conclusions about crop yield, plant health and development, as well as any change over time if

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[65] National Geospatial-Intelligence Agency, "Geospatial Intelligence (GEOINT) Basic Doctrine Publication 1.0," National System for Geospatial Intelligence, April 2018, https://www.nga.mil/resources/GEOINT_Basic_Doctrine_Publication_10_.html#:~:text=Geospatial%20Intelligence%20(GEOINT)%20Basic%20Doctrine,and%20execute%20their%20assigned%20missions. Accessed 11 March 2022

[66] Frelinger, David, & Gabriele, Mark, "Remote Sensing Operational Capabilities: Final Report," RAND, Science and Technology Policy Institute, October 1999, https://www.rand.org/content/dam/rand/pubs/monograph_reports/2005/MR1172.0.pdf

[67] U.S. Department of Justice and Drug Enforcement Administration, "Coca Cultivation and Cocaine Processing: An Overview," Office of Intelligence, February 1991, https://www.ojp.gov/pdffiles1/Digitization/132907NCJRS.pdf

[68] Clark, Robert, *Intelligence Collection*, Radiometric and Spectral Imaging, 245-275 (CQ Press, 2014). ISBN 978-1-4522-7185-9

[69] Hearn, Kelly, "Drug Cartels Siphon Pipelines – Ecuador," Pulitzer Center, *The Washington Times*, 4 June 2008, https://pulitzercenter.org/stories/drug-cartels-siphon-pipelines. Accessed 10 March 2022

[70] Bascle, Laurent, & Font, Francoise, "Illisys V2: A Solution dedicated to the monitoring of Illicit Crops," AARS, ACRS 2004, *Data Processing: Image Classification*, 2004, https://a-a-r-s.org/proceeding/ACRS2004/Papers/ICL04-3.htm. Accessed 7 March 2022

[71] Stars Project, "Multispectral and panchromatic images," Remote Sensing Technology, accessed 2 March 2022, https://www.stars-project.org/en/knowledgeportal/magazine/remote-sensing-technology/introduction/multispectral-and-panchromatic-images/

[72] United Nations Office on Drugs and Crime, "Mexico Monitoring of Opium Poppy Cultivation 2014-2015," UNODC Research, June 2016, https://www.unodc.org/documents/crop-monitoring/Mexico/Mexico-Monitoring_of_Opium_Poppy_Cultivation_2014-2015-LowR.pdf. Accessed 5 March 2022

collection is repeated.[73] Distinguishing between coca crops and other foliage could be sufficiently executed in just a few spectral bands as they have different response curves from surrounding plants or trees.[74] The analysis of MSI signatures can also extend beyond the detection of different types of vegetation – the sensors easily detect heat producers, a common characteristic of coca refinement as the leaves must be dried before being processed into cocaine.[75] Multispectral imagery can be employed to spot lamps or vehicles beneath the cover of otherwise lowly-inhabited jungle canopies. The presence of these objects is sometimes consistent with illicit agriculture operations.

In summary, an unmanned aerial system like the ScanEagle equipped with electro-optical sensor(s) capable of capturing both panchromatic and multispectral imagery would be the one of the safest and most cost-efficient approaches for analyzing and understanding coca cultivation in southeastern Peru. Collection would require sufficient light and minimal cloud cover, both factors in the development of a collection schedule (especially in the Andes, where precipitation and sunlight vary significantly).[76,77,78]

The ScanEagle spec sheet lists build options with Boeing's own EO turrets, EO telescopes, and mid-wave infrared sensors; equipping the ScanEagle with separate sensors may

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[73] National Geospatial-Intelligence Agency, "Geospatial Intelligence (GEOINT) Basic Doctrine Publication 1.0," National System for Geospatial Intelligence, April 2018, https://www.nga.mil/resources/GEOINT_Basic_Doctrine_Publication_10_.html#:~:text=Geospatial%20Intelligence%20(GEOINT)%20Basic%20Doctrine,and%20execute%20their%20assigned%20missions. Accessed 11 March 2022

[74] Clark, Robert, *Intelligence Collection*, Radiometric and Spectral Imaging, 245-275 (CQ Press, 2014). ISBN 978-1-4522-7185-9

[75] U.S. Department of Justice and Drug Enforcement Administration, "Coca Cultivation and Cocaine Processing: An Overview," Office of Intelligence, February 1991, https://www.ojp.gov/pdffiles1/Digitization/132907NCJRS.pdf

[76] Weather Spark, "Climate and Average Weather Year Round in Quince Mil," accessed 16 Feb 2022, https://weatherspark.com/y/26627/Average-Weather-in-Quince-Mil-Peru-Year-Round

[77] Frelinger, David, & Gabriele, Mark, "Remote Sensing Operational Capabilities: Final Report," RAND, Science and Technology Policy Institute, October 1999, https://www.rand.org/content/dam/rand/pubs/monograph_reports/2005/MR1172.0.pdf

[78] Clark, Robert, *Intelligence Collection*, Radiometric and Spectral Imaging, 245-275 (CQ Press, 2014). ISBN 978-1-4522-7185-9

be unnecessary should Boeing's sensors include the spectral bands necessary for this project (such information is not publicly available).[79] However, electro-optical equipment common to remote sensing applications in agriculture like the Airinov MultiSpec 4C system, the Tetracam Micro-MCA varieties, the Intergraph DMC-I Digital Mapping Camera, or the MicaSense Altum-PT are within the ScanEagle's weight limit, have customizable imagery types or bands based on mission requirements, and are good sources for comparison.[80,81,82,83,84,85,86]

[79] Insitu, "ScanEagle," accessed 18 Feb 2022, https://www.insitu.com/products/scaneagle
[80] Raeva, Paulina Lyubenova, et al., "Monitoring of crop fields using multispectral and thermal imagery from UAV," *European Journal of Remote Sensing* 52, issue sup1, 37th EARSeL Symposium: Smart Future with Remote Sensing, 10 Oct 2018, https://www.tandfonline.com/doi/full/10.1080/22797254.2018.1527661
[81] Nebiker, Stephan, & Lack, Natalie, "Multispectral and Thermal Sensors on UAVs," Capabilities for Precision Farming and Heat Mapping, GIM International, 2 August 2016, https://www.gim-international.com/content/article/multispectral-and-thermal-sensors-on-uavs. Accessed 5 March 2022
[82] Tetracam, "Imaging Systems," accessed 16 March 2022, https://www.tetracam.com/ImagingSystems.htm
[83] Berni, J.A.J., et al., "Remote Sensing of Vegetation from UAV Platforms Using Lightweight Multispectral and Thermal Imaging Sensors," Inter-Commission WG I/V, University of Cordoba, January 2008, https://www.researchgate.net/publication/237138644_Remote_sensing_of_vegetation_from_UAV_platforms_using_lightweight_multispectral_and_thermal_imaging_sensors. Accessed 1 Mach 2022
[84] Kulbacki, Marek, et al., "Survey of Drones for Agriculture Automation from Planting to Harvest," International Conference on Intelligent Engineering Systems, IEEE, 2018, https://ieeexplore.ieee.org/abstract/document/8523943
[85] MicaSense, "Sensor Comparison," accessed 3 March 2022, https://micasense.com/compare-sensors/
[86] Digital Mapping Inc., "Airborne Sensors: State of the Art Airborne Imagery and LiDAR Sensors," Intergraph DMC-I Digital Mapping Camera, accessed 6 March 2022, http://admap.com/airborne-sensor

Collection Timeline

Considering the significant activity typical of the large March harvest, the window of opportunity to collect the most informative and representative multispectral imagery lies between approximately 20 February and 10 April.[87] Because sensors capable of capturing panchromatic imagery are most useful when operating under clear skies in daytime – and because MSI targeting will be based on the analysis of PAN – it is imperative to allow ample time for PAN to be collected and analyzed before the March harvest begins.[88]

Unfortunately, December through February is the most challenging time of the year for imagery collection. For instance, the January sky is overcast or mostly cloudy 93% of the time; March begins the transition of weather patterns where cloud cover decreases gradually from a 91% to 86% chance of the sky being overcast.[89] Figure 5 is a collection timeline calculated under ideal conditions that must be executed in consideration of weather patterns.

Collection Timeline

Task	*Training*	*Collect PAN*	*Analyze PAN*	*Collect MSI*	*Analyze MSI*	*Debrief, Disseminate*
Estimated duration in hours (ideal conditions)	40	10-16	35-45	*25%:* 2-4 *50%:* 5-8 *75%:* 8-12 *100%:* 10-16	*25%:* <10 *50%:* 10-20 *75%:* 20-30 *100%:* 30-40	16

Figure 5. *Collection timeline (independent of weather).*

[87] U.S. Department of Justice and Drug Enforcement Administration, "Coca Cultivation and Cocaine Processing: An Overview," Office of Intelligence, February 1991, https://www.ojp.gov/pdffiles1/Digitization/132907NCJRS.pdf
[88] National Geospatial-Intelligence Agency, "Geospatial Intelligence (GEOINT) Basic Doctrine Publication 1.0," National System for Geospatial Intelligence, April 2018, https://www.nga.mil/resources/GEOINT_Basic_Doctrine_Publication_10_.html#:~:text=Geospatial%20Intelligence%20(GEOINT)%20Basic%20Doctrine,and%20execute%20their%20assigned%20missions. Accessed 11 March 2022
[89] Weather Spark, "Climate and Average Weather Year Round in Quince Mil," accessed 16 Feb 2022, https://weatherspark.com/y/26627/Average-Weather-in-Quince-Mil-Peru-Year-Round

At every weather-dependent stage, it is imperative to account for poor visibility and atmospherics that may hinder imagery collection. The timeline begins with 5 days allocated for intelligence briefings and training. Once collectors are adequately prepared, the UAS must be flown 125 kilometers (78 miles) to the northeast corner of the area of interest where it will collect panchromatic imagery in a north-south oscillation pattern (Figure 6, Figure 7). The final pass orients the vehicle' return flight along the northwest corner, about 145 kilometers (90 miles) from Padre Aldamiz International Airport.

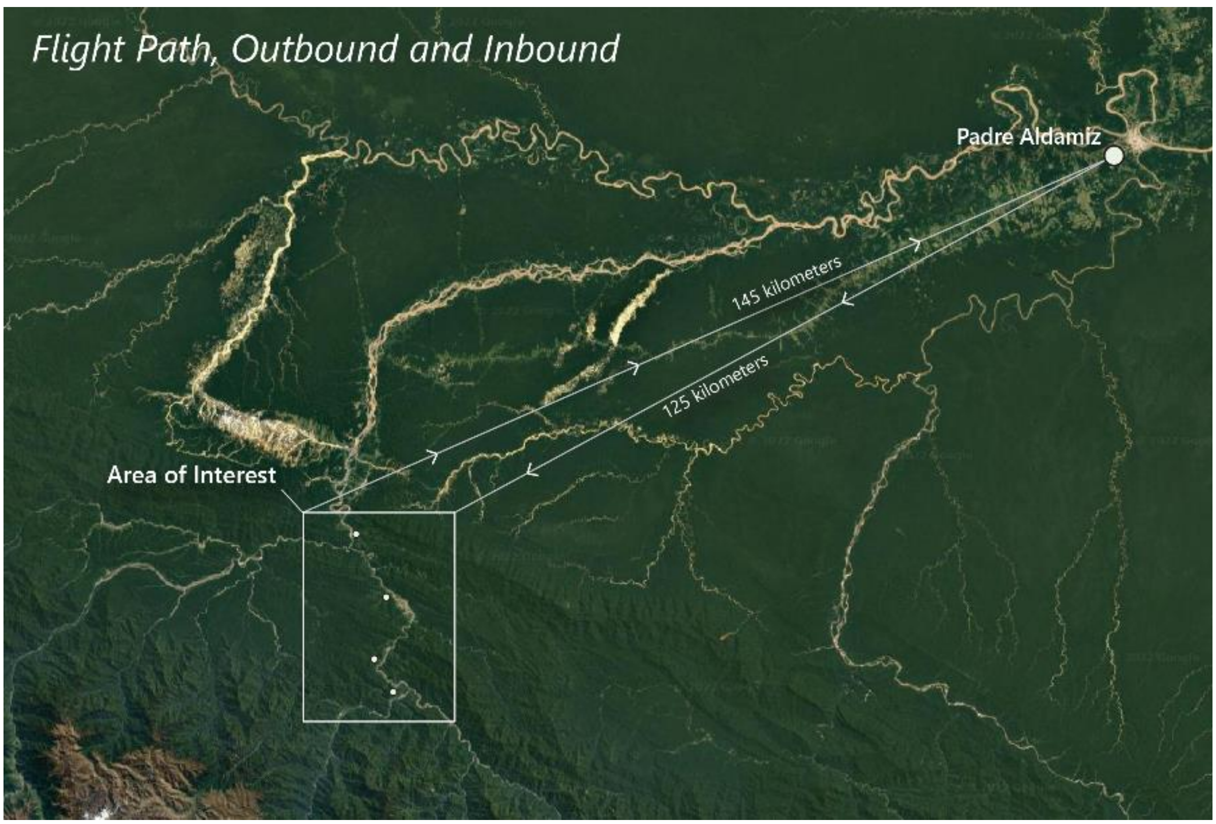

Figure 6. *Outbound and inbound flight paths.*
Courtesy of citypopulation.de, Esri, UNODC, mapcarta.com, OpenStreetMap, Google

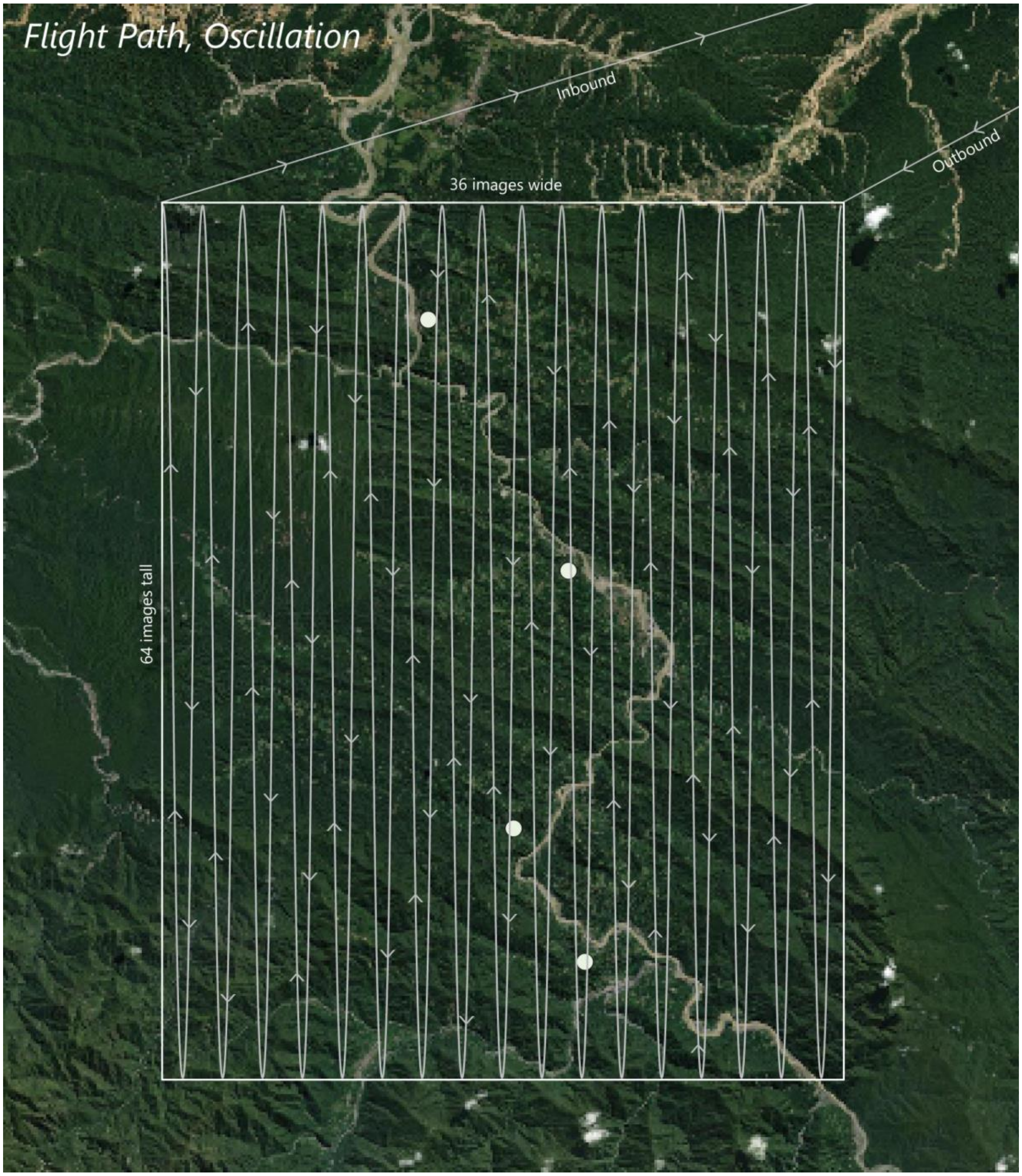

Figure 7. *North-south oscillation pattern for flight optimization.*
Courtesy of citypopulation.de, Esri, UNODC, mapcarta.com, OpenStreetMap, Google

The north-south pattern was chosen to account for minor changes in elevation as the UAS approaches the Andes and to limit the number of time-consuming turns the UAS will need to make in order to cover the area of interest. The time required to collect PAN over the 730 km^2 collection zone is based on Tetracam's Micro-MCA series camera whose images have a

635x508m field of view at an acceptable altitude for the ScanEagle (~905 meters or 2970 feet).[90] Given the ScanEagle's cruising speed of 50-60 knots (approximately 92-111 kilometers/hour or 57-69 miles/hour), it will take around 15 hours to collect panchromatic imagery if the UAS travels at a constant speed of 95 km/hr.[91] However, the aircraft can reach a maximum speed of over 80 knots (150 kilometers/hour or 92 miles/hour).[92] When not actively capturing images, the ScanEagle can reduce collection time by several hours by increasing its speed on the way to the area of interest, in-between the capture of images, and when returning.

It is very important for the UAS to increase its speed whenever possible as the average number of full daylight hours during the summer months of January, February, and March – in other words, the time at which the sun is visible and collection can occur – is around 12.[93] Further, for the 59 total days in January and February, there are only about four days that skies are expected to be clear. The ScanEagle's endurance exceeds both of these constraints; splitting collection into two passes may reduce the optimization of flight patterns and lead to a significant increase in cost, but more importantly can greatly extend the duration of the project. Ultimately, if panchromatic imagery collection is incomplete after the ScanEagle's first flight, delays could result in multispectral imagery collection to miss the March harvest entirely.

The ScanEagle is a system that includes four aerial vehicles. It is unclear if these can operate concurrently (the UAS includes one ground control station, remote video terminal, launcher, and recovery system, which may or may not be capable of managing four drones at

[90] Tetracam, "Micro-MCA Ground Resolution and Field of View," accessed 22 Mar 2022, https://www.tetracam.com/ProductsMicro_MCA.htm#:~:text=Micro%2DMCA%20systems%20are%20available,MCA6%20and%20the%20Micro%2DMCA12
[91] Insitu, "ScanEagle," accessed 28 Mar 2022, https://www.insitu.com/products/scaneagle
[92] Ibid.
[93] Weather Spark, "Climate and Average Weather Year Round in Quince Mil," accessed 16 Feb 2022, https://weatherspark.com/y/26627/Average-Weather-in-Quince-Mil-Peru-Year-Round

once).[94] Those specifications are not available to the public, but operating multiple aircraft simultaneously could significantly reduce PAN and MSI collection time if it is possible. On the other hand, if panchromatic imagery can be collected in just one day by one vehicle, it may reduce the overall cost to rent the system.

After PAN collection is finished, the imagery will need to be analyzed. Based on the Micro-MCA camera's 635x508m field of view, collection will yield around 2,300 images. The time required to analyze any given image will vary significantly, but was estimated to be one minute per image on average (some will be easy to discard, some will not). At scale, this would take approximately 38 hours; however, depending on the skill of the imagery analyst and the nature of the imagery, it may take more or less time. The 35-45 hour estimate also allows for tasking of MSI and its flight pattern optimization. It's expected for the analyst to spread out his or her work over the span of a full 5-day work week. More than one imagery analyst could be hired to expedite the IMINT analytic process, but would only be necessary should another clear day be predicted shortly after PAN collection was completed.

Because MSI collection will be informed by PAN analysis, the time required for its collection and analysis can only be estimated (Figure 5 shows 25%, 50%, 75%, and 100% for budgeting and timeline purposes). Collection results, crop vigor assessments, and other necessary reporting will then need to be disseminated in both U.S. and Peruvian intelligence communities, which is estimated to take about two days. The development of a report on the conclusions of this project can be done by a trained analyst or a technical writer, or both; it may

[94] U.S. Air Force, "Factsheets: Scan Eagle," 15 Sept 2011, https://web.archive.org/web/20130710112005/http://www.af.mil/information/factsheets/factsheet.asp?id=10468

be useful to consider hiring an additional geospatial analyst in order to better accentuate key findings to customers through maps, graphics, charts, or annotated imagery.

In conclusion, the project should begin no later than mid-January to increase the window of opportunity for clear skies and ensure MSI collection does not miss the March harvest. Further, when considering the flight path, it is important to account for the ScanEagle's turning radius to ensure the system can safely change course without needing to overlap passes (such information is not publicly available nor would be discernable until after takeoff).

Though fitting a 15-hour collection run into a 12-hour daylight window is possible, it is an ideal on all fronts. This type of collection rarely goes according to plan when conducted in a highly variable environment, so investment in contingent collection cycles with two- or even three-day durations at the PAN and MSI levels are worthwhile. Increasing speed to save time may also compromise the quality or overlap of the collected imagery. These estimates are to serve as a baseline and proof-of-concept.

Lastly, the calculations of this section exclude those of data management as the ScanEagle and Micro-MCA camera's data storage, transmission, and system compatibility details are not publicly available. The collection of ~2,300 panchromatic images and additional MSI would certainly create a data management challenge; the speed at which any system – hardware and software included – loads, recalls, maneuvers, or processes such a cumbersome dataset may extend the project timeline and add to its expected costs.

Expected Costs

The ScanEagle system cost is approximately $3.2 million (2006 dollars).[95] Adjusted for inflation of the U.S. dollar, the UAS would cost approximately $4.56 million in 2022 if purchased new but varies depending on the equipment necessary to conduct reconnaissance. If rented at 10% of the cost of the system for one year, the price would be roughly $456,000; given that collection must occur between January and the end of March, the system would only be needed for one-fourth of the year at $114,000. Additionally, the ScanEagle requires two airmen and two maintenance personnel to operate.[96] Because training is estimated to take 40 hours and that PAN and MSI should take no more than 32 hours total to collect, the cost of hiring a collection team should be no more than $15,000 (four operators at $50/hour rate of $100,000/year salary).

Comparatively, Cessna 206 airplanes are commonly used in agricultural monitoring and would be an appropriate alternative to an unmanned system.[97,98] The Turbo Stationair is the most current version of the airplane being sold on the market with a base aircraft price of approximately $745,000 – rented at 10% for one year for only 3 months, the plane would cost $18,625.[99,100] Although the cost of the aircraft is cheaper, it is not easily portable like the 45-pound ScanEagle.[101] It also does not account for the wages of a trained pilot, his or her

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[95] U.S. Air Force, "Factsheets: Scan Eagle," 15 Sept 2011, https://web.archive.org/web/20130710112005/http://www.af.mil/information/factsheets/factsheet.asp?id=10468
[96] Ibid.
[97] Yang, Chenghai, "Remote Sensing Platforms and Equipment," Agricultural Aviation, Aerial Imaging, 2018, https://www.agaviationmagazine.org/agriculturalaviation/summer_2018/MobilePagedArticle.action?articleId=1411365#articleId1411365
[98] Gabriel, Jose, et al., "Airborne and ground level sensors for monitoring nitrogen status in a maize crop," *Biosystems Engineering* 160, 124-133 (2017): https://doi.org/10.1016/j.biosystemseng.2017.06.003
[99] Air.one, "Cessna Turbo Stationair," Aircraft Showroom, accessed 8 April 2022, https://air.one/aircraft-showroom/cessna-206-turbo-stationair/
[100] Yeoman, David, "Cessna 206 Guide and Specs: Is It High Performance?" Aviator Insider, Airplane Brands, accessed 5 April 2022, https://aviatorinsider.com/airplane-brands/cessna-206-guide/
[101] Insitu, "ScanEagle," accessed 28 Mar 2022, https://www.insitu.com/products/scaneagle

hazardous duty incentive pay, or the priceless cost of pilot life when collecting geospatial intelligence in dangerous zones or mountainous terrain.[102] Collecting with an airplane would also require an imaging technician or control automation of the sensor.[103] The transportation and operating costs of an airplane would ultimately offset the costs of renting a complex – but more importantly, safer – UAS.

Regardless of airborne platform choice, the Tetracam Micro-MCA used for timeline calculations has system pricing publicly available online as of 2016.[104] The system varies in price depending on the type and its attachments, but generally falls between $13,000 – $30,000 if the camera were purchased new.[105]

To task multispectral collection, a skilled imagery analyst is estimated to take around 40 hours ($2,000 at $50/hour) to analyze panchromatic imagery and locate which areas are necessary to revisit. Assuming that panchromatic analysis yields a 100% return for multispectral imagery, the imagery analyst may take up to an additional 40 hours ($2,000, $4,000 total) to assess the crop vigor and state of coca production in the region. Lastly, it is expected to take a technical writer approximately 16 hours ($800) to construct a report intended for dissemination throughout the U.S. and Peruvian intelligence communities. Figure 8 shows the itemization of expenses and total expected cost to execute a collection plan similar to what has been described in this paper.

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[102] U.S. Department of Defense, "Hazardous Duty Incentive Pay (HDIP)," Military Compensation, Pay, Special and Incentive Pays, accessed 7 February 2022, https://militarypay.defense.gov/Pay/Special-and-Incentive-Pays/HDIP/
[103] Lan, Yubin, et al., "Current status and future directions of precision aerial application for site-specific crop management in the USA," *Computers and Electronics in Agriculture* 74, no. 1, (2010): 34-38, https://doi.org/10.1016/j.compag.2010.07.001
[104] Tetracam, "Tetracam System Pricing," 1 April 2016, accessed 6 April 2022, https://www.tetracam.com/PDFs/Current_System_Prices.pdf
[105] Ibid.

Expected Costs

Itemization	***ScanEagle System*** *(10% rental, 25% of the year)*	***Tetracam Micro-MCA*** *(Most expensive sensor system estimate)*	***Collectors*** *(training, collection of PAN and 100% MSI for 4 UAS employees)*	***Imagery Analyst*** *(PAN, 100% MSI)*	***Technical Writer*** *(2 days to disseminate)*	***TOTAL***
Expected Cost (USD)	$114,000	$30,000	$15,000	$4,000	$800	**$163,800**

Figure 8. *Expected costs*.

Though the price estimation covers general equipment and primary personnel, there are expected to be additional expenses (e.g., travel and housing for employees, the pay for a project lead, fuel or repairs); however, the total cost of the project should remain under $200,000.

Discussion and Future Considerations

In commercial agriculture, it is common to use helicopters or satellites to collect intelligence. However, the choice to use an unmanned aerial system for this project is largely due to safety, but also due to cost. The expense of using a satellite may be offset if conducting a wide-area search, but the area of interest in this case is not large enough. Depending on the kind of space-compatible sensor, there also may not be high enough resolution for its collection to be useful. Additionally, given that the number of days with weather acceptable for collection is so small, collecting below the cloud base ensures the least amount of weather-related interference and rules out the use of satellites entirely.

The automation of object recognition through machine learning (crop or anomalous activity identification, for instance) is likely to become more common, reliable, and affordable in the coming years as the geospatial intelligence tradecraft continues to advance. Currently, there are already functional models for species identification, plant disease detection, and even yield forecasting specifically for coca crops in Colombia.[106,107,108] Additionally, improvements in object detection through AI/ML in data collected from low-altitude UAVs are also being made.[109] Automating the analytic processes may help reduce costs and expedite the project.

Though this collection plan is

[106] Sun, Yu, et al., "Deep Learning for Plant Identification in Natural Environment," *Computational Intelligence and Neuroscience*, 22 May 2017, https://doi.org/10.1155/2017/7361042
[107] Yadav, Saumya, et al., "Identification of disease using deep learning and evaluation of bacteriosis in peach leaf," *Ecological Informatics* 61, 2021, https://doi.org/10.1016/j.ecoinf.2021.101247
[108] Saleem, Muhammad Hammad, et al., "Image-Based Plant Disease Identification by Deep Learning Meta-Architectures," *Plants* 2020, 9(11), 1451, 27 October 2020, https://doi.org/10.3390/plants9111451
[109] Mittal, Payal, et al., "Deep learning-based object detection in low-altitude UAV datasets: A survey," *Image and Vision Computing* 104, 2020, https://doi.org/10.1016/j.imavis.2020.104046

Lastly, it is important to remember that Peruvian coca is grown in more than a dozen areas countrywide and that this paper only focuses on one of them.[110] Further, Peru is not the only country subject to newfound demand in the wake of landmark legislation in Colombia; other nations like Bolivia may also experience significant impact in the coming years and should be similarly monitored for change. Coca, of course, is also not the only instance of illicit agriculture with international impact. For example, Opium grown in Afghanistan, Myanmar, and Mexico or cannabis cultivated in Nigeria have their own sociocultural consequences for individuals involved in narcotrafficking in addition to international effects for both smugglers and drug users.[111] Future work should continue to evaluate instances of illicit agriculture beyond coca crops – or shifts in the drug market outside of Central and South America – to more comprehensively prevent corruption, terrorism, the destruction of vulnerable communities, and the loss of innocent life.

[110] United Nations Office on Drugs and Crime, UNODC ICMP, DEVIDA Comision Nacional para el Desarrollo y Vida Sin Drogas, "Peru Monitoreo de Cultivos de Coca," *UNODC and illicit crop monitoring,* UNODC Research, 2003-2018. https://www.unodc.org/unodc/en/crop-monitoring/index.html?year=2021
[111] United Nations Office on Drugs and Crime, "UNODC and illicit crop monitoring," accessed 15 April 2022, https://www.unodc.org/unodc/en/crop-monitoring/index.html

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