REMOTE SENSING IN IBERÁ WETLANDS, ARGENTINA: UNCREWED AIRCRAFT SYSTEMS AND SERVICE LEARNING SUPPORTING ENVIRONMENTAL RESILIENCE

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ABSTRACT

Mapping wetland regions is challenging. Uncrewed aircraft systems (UAS) have inherent abilities to rapidly and efficiently remotely sense difficult to access locations. Wetland regions around the world are under pressure due to increasing human presence and climate change. The Iberá Wetlands in Argentina is an example of a region that greatly rebounded from detritus effects from human activity. Although the Iberá Wetlands suffered great environmental degradation with numerous large animals being driven from the region, visitors today see a biologically diverse region bearing the fruit of restoration. It serves as a prime location for demonstrating the ability of UAS to efficiently collect data to monitor the environment. A team traveled to the Iberá Wetlands to work with local stakeholders with a common interest in the health of the regional environment. The team flew UAS equipped with RGB and multispectral cameras with local stakeholders. The UAS could generate vegetative indices in real time for viewing as well as record video and still images for post hoc analysis. The team worked with concerned parties from the local community and agencies from the nongovernmental sector to gather and show how UAS could readily collect data facilitating the understanding of the Iberá Wetlands and its current state of being.

Keywords: UAS; remote sensing; wetlands; service learning; NDVI; Iberá

INTRODUCTION

Wetland communities across the world are grappling with a need to better understand, mitigate, and adapt to the interlinked environmental stressors caused by increasing human presence and climate change driven effects. The Iberá Wetlands in Argentina are an example of wetlands under stress, and an example of implemented responses designed to restore the natural environment while enhancing its resilience. Environmental resilience addresses understanding and managing the impacts of change while preventing those impacts from growing worse. The Iberá Wetlands have some unique stressors and ensuing tailored responses that included restoration of natural waterflow and reintroduction of animals. Uncrewed aircraft systems (UAS) (i.e., drones) have applications for gathering data through remote sensing that enables real-time data gathering for interpretation and presentation to concerned stakeholders. University students, while studying abroad, participated in operational phases of UAS missions for remote sensing to include planning, preparing aircraft and sensors, collecting data, and processing data. Data were prepared into photogrammetric products and imagery for local stakeholders and the international community. The data helped educate about readily available remote sensing technologies and the positive effects that restoring the Iberá Wetlands has on livelihoods in rural communities.

UAS are ideal platforms for remotely sensing critical wetlands due to the inherent advantage of aerial perspective, flexible application for hard to access locations, and precise flight path management (Davis et al. 2022). Innovative applications of UAS are made possible by the ever-increasing power of microprocessors and increases in data bandwidth; these technological advantages are occurring while relative costs decrease for levels of computing power and increasing bandwidth (Macchiarella et al. 2019a). Intelligent automation makes ultra-precise flight path control and navigation possible for UAS. A UAS provides users with a versatile remote sensing platform that can attain vantage points that were impossible in the past with manned aircraft or terrestrial means. Imagery obtained by remote sensing during UAS flight is being used in varying instances to create orthomosaic maps with levels of detail previously unavailable. Multispectral imaging enables rapid assessment of the health and wellbeing of plant life. Furthermore, UAS obtained imagery can be processed using photogrammetric techniques to create three dimensions of data for developing digital surface models (DSM),

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and terrain visualization through 3D virtualization. Hence, UAS obtained data and derived products can aid in understanding the environment.

Mapping wetlands is challenging (Jeziorska 2019). The physicality of the surface (i.e., diversity and concentration of vegetation combined with water saturation and surface instability) makes access by ground vehicle and boat difficult. Aerial platform mobility is unaffected by wetland surface conditions. Traditional piloted aviation and satellites can serve as solutions; however, both are associated with higher cost and lower temporal and spatial resolutions. Higher spatial resolution pictures, higher temporal frequency, relative ease of use, and flexibility of deployment are hallmarks of UAS when used for remote sensing imagery. Specifically, the National Oceanic and Atmospheric Administration (NOAA) determined that, "UAS are a valuable addition to wetland monitoring efforts and will dramatically increase the ability to detect change at the temporal and spatial scales that are important to wetland scientists and managers" (Davis et al. 2022).

A team composed of faculty, students, and local nationals participated in a study abroad service-learning project in the Iberá Wetlands. The team flew UAS equipped with multispectral and RGB cameras over the wetlands during June 2024 to help gauge the impact of conservation efforts. The data were processed to determine vegetation reflectance values in visible light and infrared. Images were converted into orthomosaics and normalized difference vegetative index (NDVI) maps to demonstrate the ability to comprehensively assess vegetative health in a targeted portion of the Iberá National Park. This effort aimed to assess the impact that conservation efforts have had on the region and demonstrate UAS as a valid tool for performing environmental monitoring in these remote regions. These efforts highlight the contribution that innovative uses of UAS have for guiding conservation strategies and managing sustainable land practices in an ecologically significant wetland.

University students from three different aerospace-related undergraduate degree programs participated as members of multidisciplinary teams. The teams accomplished group projects centered on learning outcomes associated with applying UAS for remote sensing in a wetland environment. Teams analyzed given problems for data collection that could be solved using UAS platforms and sensors. Students determined and implemented the steps that were necessary for collecting data, analyzing data, drawing conclusions, generating usable information, and making presentations to stakeholders in the region. The nature of assigned teamwork required capturing multispectral and visible light imagery that documented the current environmental health of select areas.

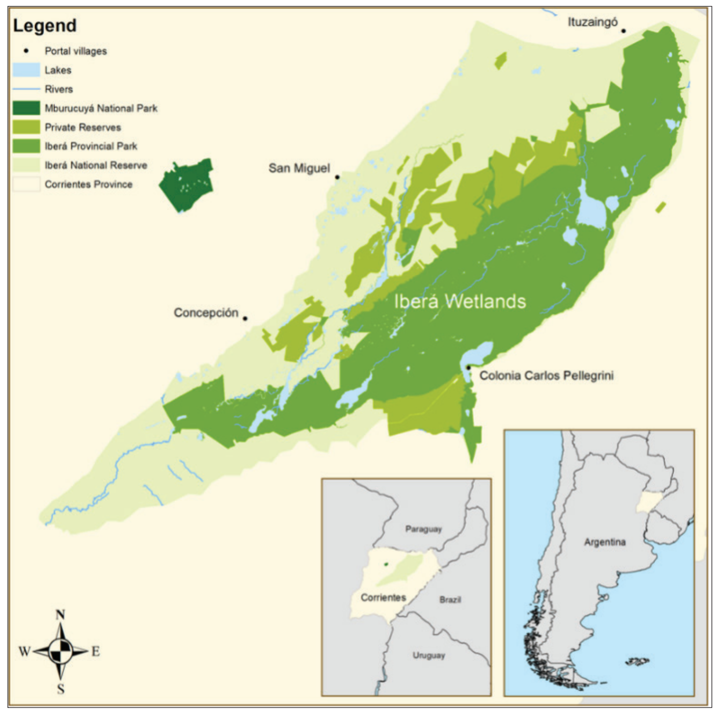

Figure 1. Iberá Wetlands located in Argentina (Pettersson and de Carvalho 2021)

THE IBERÁ WETLANDS AN ENVIRONMENTALLY IMPORTANT REGION

Background

Situated in northeastern Argentina, the Iberá Wetlands stand as the world's second-largest wetland with a size of over 13,000 square kilometers, hosting a remarkable array of over 4,000 plant and animal species, and representing 30% of the nation's biodiversity (Allen 2023). Despite its ecological significance, this remote region faces challenges arising from climate change and human activities. Commercial foresting, poaching, and cattle ranching significantly degraded the region to the point that several species—including jaguars, giant otters, tapirs, and giant anteaters—had completely vanished, and several more species faced the same fate

(Allen 2023). To address these concerns and ensure the preservation of this critical ecosystem, the Iberá Provincial Park was established in 1983, signifying a strategic commitment to conservation and sustainable management practices, including the reintroduction of key species and the promotion of ecotourism.

The Iberá Wetlands have historically faced threats from climate change and human activities. Extensive conservation efforts, led by organizations like the Rewilding Argentina Foundation and the Argentinian government, have successfully revitalized the region (López 2022). Noteworthy achievements include the reintroduction of key species and enhancements in local plant life through sustainable farming practices and restoring water flow.

Between December 2022 and February 2023, the Iberá Wetlands suffered a large wildfire burning over 5200 square kilometers or over a third of its total area (Cassidy 2023). The contributing factors to the fire's generation were a prolonged drought and high temperatures that were attributed to climate change and the La Niña weather pattern. The fire greatly impacted conservation efforts, but despite this setback, the region continues to be revived. Continuing assessment of the progress of conservation efforts, amid temporary setbacks and climate change is important. These continuing assessments provide crucial information that is necessary for making informed decisions that help to increase the resilience of the wetlands.

Importance

In 2015, member nations of the United Nations (UN) adopted Sustainable Development Goals. The goals aim to protect the world's environment from human-induced effects and climate change. Biodiversity loss is an environmental problem for nations to mitigate. Terrestrial ecosystems are essential elements to overall health and viability of the land for supporting humanity. UN Sustainable Development Goal 15 addresses Life on Land. It describes healthy land environments, challenges, and solutions (United Nations Environment Programme 2015). Maintaining soil quality, enabling biodiversity, preserving water quality, regulating proper water flow, and implementing erosion control all help reduce possibilities of natural disaster (e.g., floods, landslides). These efforts help the climate while maintaining agricultural productivity. Preserving healthy ecosystems greatly supports mitigation of climate change and adaptation efforts to help local communities thrive in a world of increasing environmental pressures.

The Iberá Wetlands represents an extremely ecologically significant region for Argentina and the entire world. The wetland contains over 30% of the nation's total biodiversity while only making up a small fraction of the of the country's landmass (Allen 2023). The wetlands are densely packed with vegetation and wildlife that are faced with threats from climate change and human activities. The protection of this region is imperative for preserving native animals. Over the years, many restoration and conservation efforts have been undertaken to bring the wetlands back to health and save several species from extinction in the region (López 2022). Locally extinct species included the giant anteater, tapir, collared peccary, pampas deer, ocelot, giant river otter, and jaguar. Restoration efforts have successfully reintroduced these animals to the region.

Restoration

Through the conservation efforts of Doug and Kristine Tompkins, Conservation Land Trust, and later Rewilding Argentina Foundation, the area covered by the Iberá Provincial Park was expanded significantly into the largest protected wetland in the country. It includes 7,580 square kilometers. The Rewilding Argentina Foundation allowed the region to return from biodiversity loss that was caused mainly by agriculture practice and overhunting. The ongoing restoration effort has reintroduced animal species, restored water flow, and enhanced the health of local vegetation. The Iberá Wetlands now consists of replenished wetlands that teem with traditional wildlife (López 2022).

LOCALES FOR UAS OPERATIONS

Two sites were chosen as representative of the land use in the wetlands. These locations supported a robust sample for data collection while serving as an exemplar of the overall conditions in the Iberá Wetlands. The first site is a mixed-use location consisting of a cattle ranch and wetlands environment. This site represents the cohabitation of human activities and conservation areas, including sustainable farming and grazing practices along with ecotourism. The pasturing fields are regularly cycled to prevent overgrazing and allowing fields to regenerate over time. The second site is purely a conservation region with a focus on ecotourism. The area presents a minimalization of human activity and is well preserved in its natural state. It generates revenue from ecotourism to help continue conservation efforts. The site consisted of a small building facility that is surrounded by nature trails and the wetlands environment. This location provided the most encounters with native wildlife and often serves as an area to introduce visitors to the local ecosystem.

CAMERA TECHNOLOGIES

The DJI Mavic 3M (DJI 2024) served as the primary UAS for remotely sensing the selected areas (DJI 2024). Its compact form factor and weight of 951 grams makes it easy to transport and take to remote locations by various means to include kayak and horseback (Figure 2). The DJI Mavic 3M integrates both an RGB camera and four multispectral cameras that are sensitive in green, red, red edge, and near infrared (Tables 1 and 2). The combination of these cameras allows for highly detailed RGB and multispectral imagery to be captured simultaneously. The UAS supports viewing the RGB camera and processed vegetative indices (e.g., NDVI) in real time.

Figure 2. DJI Mavic 3M, left, and hand controller, right.

Attribute	Specification
Image Sensor	4/3 CMOS Effective Pixels: 20 MP
Lens	FOV: 84° Equivalent focal length: 24 mm Aperture: f/2.8 to f/11 Focus: 1 m to ∞
ISO Range	100-6400
Shutter Speed	Electronic shutter: 8-1/8000 s Mechanical shutter: 8-1/2000 s
Image Size	5280×3956

Table 1. Mavic 3M RGB camera specifications (DJI 2024)

Attribute	Specification
Image Sensor	1/2.8-inch CMOS, effective pixels: 5 MP
Lens	FOV: 73.91° (61.2° x 48.10°) Equivalent focal length: 25 mm Aperture: f/2.0 Focus: Fixed Focus
Multispectral Camera Band	Green (G): 560 ± 16 nm; Red (R): 650 ± 16 nm; Red Edge (RE): 730 ± 16 nm; Near infrared (NIR): 860 ± 26 nm;
Shutter Speed	Electronic Shutter: 1/30~1/12800 s
Max Image Size	2592×1944
Video Format	MP4 (MPEG-4 AVC/H.264)
Video Resolution	H.264 FHD: 1920 x 1080@30fpsse Video content: NDVI/GNDVI/NDRE

Table 2. Mavic 3M Multispectral camera specifications (DJI 2024)

FLIGHT METHODOLOGY

Automated flight transects and free-flight missions were used to collect aerial imagery. Images captured by the UAS were processed using commercially available Structure-from-Motion (SfM) software, Pix4Dmapper Pro (v. 4.9.0) (Pix4D 2024a). The resulting high-resolution orthomosaic image was 18.7 times more detailed than commonly available satellite imagery.

The orthomosaic was produced using photogrammetry, a process that creates spatially accurate, map-like images by stitching together multiple overlapping photos (Figure 3). Photogrammetry is defined as "the art and science of obtaining useful information from the environment by processing imagery and then applying exacting measures that can provide 3D characteristics" (Macchiarella et al. 2019a).

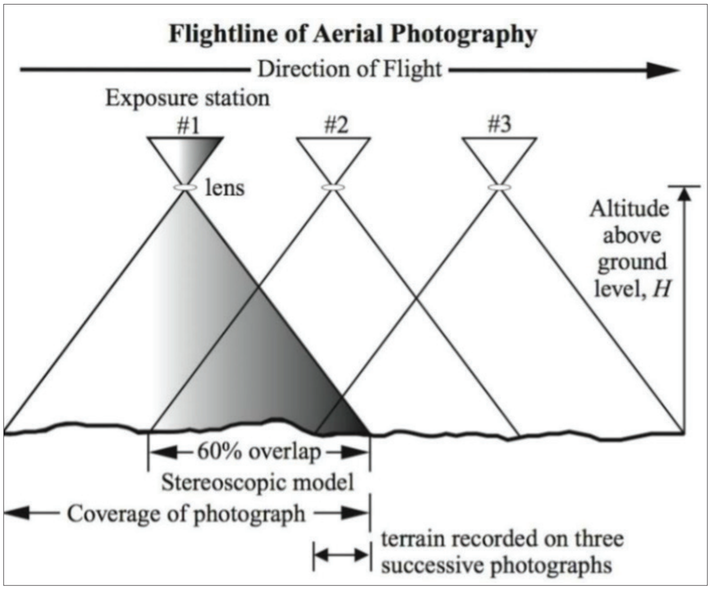

Figure 3. Representative transects for automated positioning of drone to create image overlap enabling SfM parallactic perspectives (Jensen 2007)

INDICES AND VISUALIZATION

The Mavic 3M's multispectral camera supports the creation of several indices for determining plant health. The most common vegetative index for assessing plant health is the NDVI. Plants strongly absorb visible light (from 400 nm to 700 nm) for use in photosynthesis. Conversely, the plant leaf cell structure strongly reflects near-infrared (NIR) light (above700 nm to 1100 nm) because of photosynthesis (Weier and Herring 2000). The combination of NIR with red bands is often adopted for biomass estimation, canopy structure, and assessment of specific plant health. The NDVI formula is (NIR-RED)/(NIR+RED). These indices and ratios between bands are normalized, obtaining values that range between –1 and +1, and allow the use of thresholding values to differentiate between distinct land covers (e.g., a value of NDVI greater than 0.4 usually indicates the presence of live vegetation) (Bevington et al. 2018). Also, Mavic 3M also allows a real-time view of vegetation indices (e.g., NDVI).

SERVICE LEARNING

Overview

Service learning is a dynamic and impactful form of experiential education in which students acquire knowledge and skills through active engagement in real-world tasks that address specific, identified community or societal needs. Unlike traditional classroom instruction, service learning integrates meaningful service activities with structured opportunities for reflection, critical analysis, and the application of academic content. In this pedagogical model, learning objectives are central—they shape the design of the learning experience and define clear, measurable outcomes for students. According to Astin and Sax (1998) and Caspersz and Olaru (2017), this approach fosters not only the achievement of academic goals but also a deeper and more authentic understanding of the subject matter, as students recognize the relevance and broader implications of their work.

Rather than being an add-on to existing curriculum, service learning reframes education as an interactive and transformative event. It challenges students to think beyond theoretical knowledge, encouraging them to apply their learning in ways that generate tangible benefits for individuals, communities, or partner organizations. As Aceves and Aceves (2008) argue, service learning represents a paradigm shift where education and community needs intersect, thereby cultivating a sense of social responsibility and mutual benefit.

Within aerospace and aviation disciplines, service learning is particularly well-suited to fields that emphasize applied technologies, such as the use of UAS for environmental remote sensing. These tools offer students the opportunity to execute real-world missions in authentic environments, reinforcing technical competencies while simultaneously contributing to meaningful data collection and analysis. For example, in the service-learning project conducted in the Iberá Wetlands of Argentina, student missions were directly tied to ecological monitoring goals. These missions provided valuable environmental data to local stakeholders while offering students hands-on experience in mission planning, data acquisition, and sensor integration.

Assessment plays a critical role in maximizing the educational value of service learning. Both formative and summative assessments are used to evaluate student progress and ensure alignment with instructional goals. Formative assessments, conducted during the execution of UAS missions, provide timely feedback that helps refine skills and correct misunderstandings in real-time. Summative assessments, on the other hand, are conducted after the completion of a project or mission set and measure student achievement against established performance standards. These assessments verify that students have met intended learning outcomes, including technical proficiency, problem-solving ability, teamwork, and effective communication.

The Iberá Wetlands project illustrates how experiential missions tied to service-learning principles can result in positive educational gains. Under faculty supervision, students achieved mission readiness and ultimately demonstrated competence in conducting remote sensing operations in ecologically sensitive areas. They were also able to engage with local communities, enhancing both their technical and interpersonal skills. The dual benefit of meeting academic objectives while providing actionable information to local stakeholders exemplifies the multifaceted value of this instructional strategy.

A growing body of research supports the broad and lasting benefits of service learning. Bettencourt (2015), building on earlier work by Astin and Sax (1998), found that participation in service-learning projects significantly enhances students' domain-specific knowledge, cultivates vital life skills, and promotes civic engagement. Further studies have highlighted additional gains, including personal development, improved interpersonal communication, stronger leadership abilities, and enhanced career readiness (Macchiarella et al. 2019b). Moreover, service learning can be particularly effective in immersive, cross-cultural contexts where students also gain language proficiency, cultural awareness, and the ability to integrate interdisciplinary knowledge across diverse subject areas (Gebert et al. 2019).

In summary, service learning is a powerful instructional strategy that blends academic rigor with practical application. In higher education, it offers a pathway for students to become not only competent professionals but also socially engaged and globally conscious citizens. When thoughtfully implemented, service learning deepens academic learning, strengthens community ties, and equips students with the competencies needed to address real-world challenges in meaningful and lasting ways.

Local Stakeholders

Three principal local stakeholders in the Iberá Wetlands directly benefited from the service-learning project: a working cattle ranch, a local elementary school, and an ecotourism operation. The broader community also derives significant economic benefit from ecotourism, which serves as a key driver of sustainable development in the region.

The profitability of ecotourism plays a critical role in justifying governmental and non-governmental investments aimed at establishing an "ecologically complete" national park (Pettersson and de Carvalho 2021). By involving area residents in the development and operation of sustainable businesses, ecotourism can help strengthen communities. This engagement not only supports job creation but also contributes to the preservation of local culture and traditions.

Moreover, ecotourism has the potential to raise environmental awareness among both visitors and locals. It fosters a deeper understanding of ecological issues, promotes respect for nature, and encourages the protection of natural surroundings, all while delivering enriching experiences to tourists. Through this multifaceted impact, ecotourism serves as a powerful tool for conservation, education, and community development.

The Buena Vista Estancia is a working cattle ranch in the Iberá Wetlands. The ranch also hosts ecotourism activities as a supplemental economic endeavor. These activities help to build environmental and cultural awareness and provide financial benefits for conservation. The ranch staff were oriented to UAS for remote sensing (Figure 4).

Figure 4. Left: Rancher examining drone with university student during a service-learning event. Right: Local elementary school students participating in a remote sensing flight.

Escuela Albergue Nº 364 is a small rural public elementary school that is located adjacent to Bueno Vista Estancia. Rural education in Argentina largely occurs in a multigrade teaching setting. The students from Escuela Albergue Nº 364 were included during UAS operations and provided with orientation activities that allowed hands-on UAS flight experience, application of remote sensing, and exposure to the possibilities made available by drones (Figure 4).

Puerto Galarza is a commercial ecotourism activity that provides tours through the estuaries and lagoons of the Iberá Wetlands. Tour activities include bird watching, boat rides, flora and fauna lectures, and walks through estuaries, grasslands, and native forests (Figure 5). The tour guides provide educational experiences that elucidate to visitors how organisms in the wetlands interact in a semi-aquatic zone with both water and dryland characteristics. The present state of wetland health and biodiversity are directly observable.

Figure 5. Ecotourism boat transitioning through the Iberá Wetlands.

International Engagement

The Brevard Zoo, located in Melbourne, Florida, USA, is engaged in conservation, community outreach, and education. University students remotely sensing the Iberá Wetlands for service learning connected in real time with zoo summer camp students. The educational event included live-casting UAS video conferencing of the wetlands, wildlife, and on location participants. Through the live cast, a guided discussion with online videoconferencing software occurred. The zoo summer camp students participated in question-and-answer sessions. Specifically of interest were animals like the capybara (Figure 6) that live both at the zoo and in the Iberá Wetlands. Zoo summer camp students were familiarized with UAS operations in wetlands and how drones are uniquely suited for remote sensing in difficult to reach locations. This learning experience was enriching for the zoo summer campers, and it reinforced the need to protect and preserve the Iberá Wetlands and conversely wetlands globally.

Figure 6. Wild capybara located in the Iberá Wetlands.

REMOTE MONITORING IBERÁ WETLANDS FOR ENVIRONMENTAL RESILIENCE

Two NDVIs, One Camera

The Mavic 3M drone can generate live, real-time NDVI visualizations using video from its multispectral camera, while also capturing high-resolution still images for later post-processing. Post-processing generated an indexed NDVI map, using red and near infrared images, and an orthomosaic based on RGB images with SfM software (Figure 7). Figure 8 shows drone positions, where still images were captured during programmed flight above the working area of the Buena Vista Estancia. Captured still images were processed using SfM methods with Pix4Dmapper Pro.

Two Types of Sites: Mixed Use Wetland with Cattle Ranch and Natural Wetlands

Two sites were analyzed during the project. One site was a cattle ranch embedded in the wetlands and the other location comprised purely preserved wetlands. Both sites offered unique perspectives of how regenerative efforts were fruitful in restoring and subsequently maintaining the health of the wetlands. The cattle ranch demonstrated the effects of sustainable farming practices while the natural wetlands demonstrated the effects of conservation and preservation with human presence in the form of ecotourists.

Buena Vista Estancia Mixed Use Wetland

The cattle ranch included a central area of buildings with a residence and equipment facilities surrounded by various fields for mixed uses (e.g., temporary holding of animals and hosting ecotourist activities). The associated fields and surrounding wetlands were imaged with programmed flight to ensure parameters were obtained for virtual models, orthomosaic development, and production of an indexed map of vegetative health that are all products of post-processing (Figures 7 and 8). The flight patterns were lawnmower-like (i.e., back and forth rows). The programmed flights occurred at a height of 29 meters altitude above takeoff (ATO). The post-processing project yielded an average ground sampling distance (GSD) of 0.83 cm per pixel with root mean square positional error in meters with values of $x = 0.497$, $y = 0.574$, and $z = 0.664$. Due to this project's nature, positional accuracy was adequate using the inherent precision of global navigation satellite systems. No further positional enhancements were required (i.e., real-time kinematic or post-processed kinematic). Live RGB imagery and multispectral imagery of the NDVI were also obtained to allow examination of these same areas in real time with local stakeholders (Figures 10, 11, and 12).

Both post-processed and live NDVI deliver useful information that is derived from the same camera multispectral sensor. Examining the post-processed NDVI index map of the cattle ranch (Figure 7) shows that highly grazed areas are evident and clearly identifiable indicating lower IR reflectance using the applied traditional indexing scale. Green indicates lower IR reflectance and lower health vegetation when using a traditional indexing scale. The red, or healthy, areas are typically fields that are either unused or only lightly grazed by livestock, and are covered with trees, wetland shrubs, and grasses. The live NDVI paints a similar picture. The healthy regions are indicated in red, while the less healthy regions are colored green. Water and other surfaces are indicated in black or blue. The live images corroborate the post-processed NDVI index map, for the same locations, by indicating heavily grazed areas as less healthy regions. However, the live NDVI does show more context of the surrounding environment than the NDVI index map or RGB orthomosaic due to its oblique perspectives (Figures 10 and 11). However, planar and nadir examination angles provide the viewer with a comprehensible image of a location that is 2D and map like. Oblique perspectives provide foreground and surrounding scenes placing the area of interest in context. The live NDVI captures the relatively dense vegetation surrounding the cattle ranch and identifies it as a healthy environment. The live NDVI also provides a more detailed view of the surrounding trees, including those that have lost their leaves due to seasonal change (i.e., it is fall in the southern hemisphere). The trees lacking leaves are clearly identified as green, standing out from the surrounding healthy trees, which are colored in red. The trees unaffected by seasonal changes, confirmed with the RGB orthomosaic, were evergreen trees and shrubs. The imaging occurred during June in the southern hemisphere. Due to the latitude and local geography, fall and winter conditions are very mild in temperate northern Argentina. The adjacent wetlands, visible in the background of Figure 9, display varying levels of healthy vegetation, with no visibly dead or barren areas.

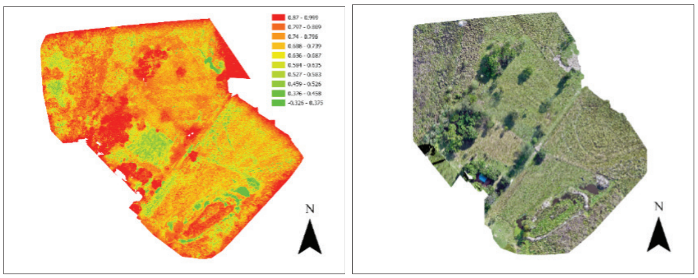

Figure 7. Left: Post-processed NDVI map. Right: Orthomosaic of mixed-use wetland at the Buena Vista Estancia (Pix4D 2024).

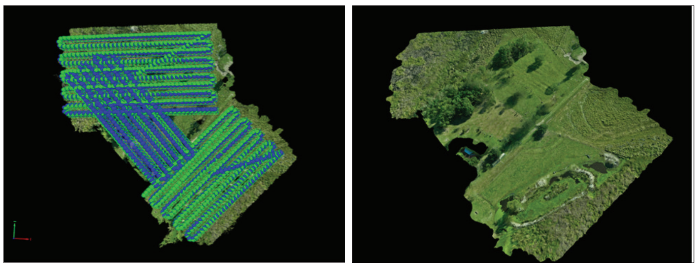

Figure 8. Left: UAS camera locations depicted above point cloud. Right: A triangle mesh of the mixed-use wetland at the Buena Vista Estancia (Pix4D 2024).

The central area of buildings (Figure 9) contains Locations A, B, and C each with a vector arrow indicating camera positions and viewing directions. Location A (Figure 10) shows the main ranch building as seen from the northwest while facing southeast. The wetlands visible at the top of Figure 10 correspond to the southwest section of the orthomosaic shown in Figure 9. Additionally, in both figures, healthy and unhealthy trees are discernable in the area surrounding the main building. One deciduous tree is noteworthy. Location B, facing southeast (Figure 11), shows a communal field adjacent to a corral. The ground of the communal field is worn and indicates lower health due to use from recreational activities. This is shown by the RGB and NDVI imagery (Figure 11). Location C (Figure 12) provides a nadir view of the main ranch building, small shed, and two vehicles while facing southwest. The three locations display different land uses and their appearance in RGB and multispectral imagery from both a post processed orthomosaic nadir perspective and live viewing perspective.

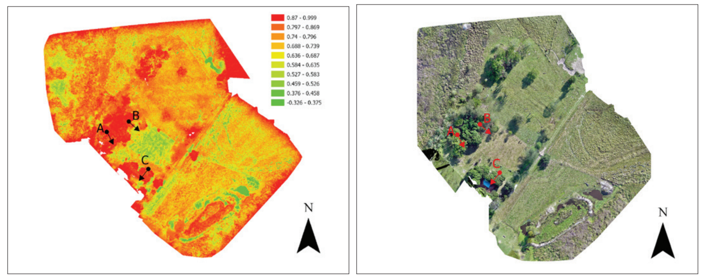

Figure 9. Left: NDVI indexed map of reflectance values. Right: RGB orthomosaic at the main ranch site with location markers of the three live images with view orientation at Locations A, B, and C (Pix4D 2024).

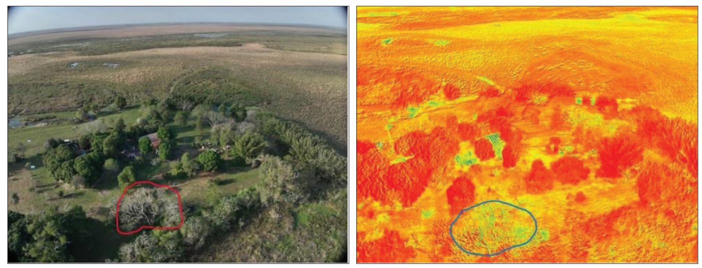

Figure 10. Live image Location A in RGB (left) and NDVI (right) of wetlands abutting main ranch site with noteworthy tree – oblique angle.

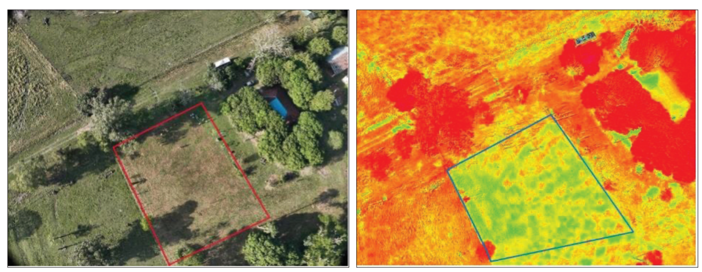

Figure 11. Live image Location B in RGB (left) and NDVI (right) of the adjacent recreational field at the main ranch site – oblique angle.

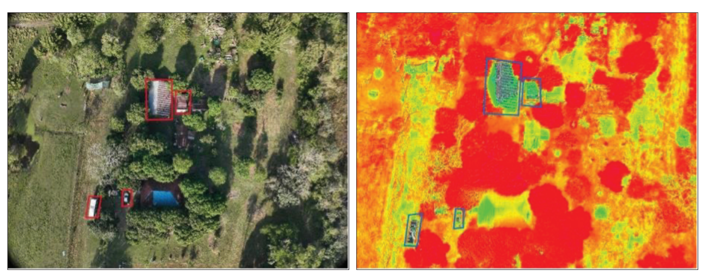

Figure 12. Live image Location C in RGB (left) and NDVI (right) of the central building at the main ranch site with rooftops and vehicles – nadir angle.

Puerto Galarza Natural Wetlands

The natural wetland site is characterized by a wide variety of vegetation, open tracts of water, and canals (Figure 13). The live RGB imagery clearly shows a difference between water, bare land, and vegetation. The live NDVI easily distinguishes between the denser soil-based vegetation, shown in red, and the thinner suspended algae, shown in green (Figure 13). The cause of this distinction is that the soil raises the plants out of the water, allowing for the full reflectance values to reach the sensor. Algae can also be monitored using RGB and multispectral sensors. The purpose of the UAS operation over the Iberá Wetlands was not to fully assess the vegetative health of the region, but to demonstrate the technology to local stakeholders and assess possibilities using vegetative indices like NDVI. The inherent ability of the Mavic 3M's multispectral camera in NIR, 860nm ± 26 nm, allows some data collection ascertaining the presence of algae and its proliferation. Studies by Pokrzywinski et al. (2022) and Cannizzaro et al. (2019) provide greater detailing on the remote sensing possibilities afforded by hyper and multispectral sensors mounted on drones and flown at wetlands of interest. UAS significantly reduces the time cost of collecting data for algae.

An orthomosaic and NDVI index map was not produced at this location. The decision was made to focus upon the live NDVI to examine the area based upon the interest and needs of the local collaborators. The homogeneous nature of the vegetation and abundance of water makes image mosaicking challenging in this type of wetland, but possible. Live RGB and NDVI imaging occurred at an altitude of 29 meters. If mosaic images are desired for locations with highly homogeneous coverings, increasing flight altitude opens the camera's field of view (FOV) (Pix4D 2024). This increased FOV affords greater possibilities of capturing features that support the stitching of individual images into a mosaic. Also having large degrees of image overlap (e.g., 75% frontlap and sidelap, or greater) greatly assists with stitching. Altitude always represents a functional tradeoff between resolution (i.e., GSD) and mission flight time. One photogrammetric advantage for imaging wetlands is that the flatness lends itself to rectification.

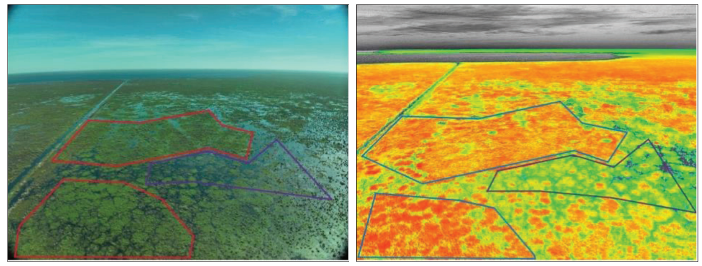

Figure 13. Live RGB (left) and live NDVI (right) images of natural wetland at Puerto Galarza with examples of denser soil-based vegetation outlined, and suspended algae, outlined in purple.

Comparison of Post-Processed NDVI Map and Live NDVI Image

Multispectral data is crucial for assessing and monitoring vegetation (Pappalardo and Andrade 2022). Live NDVI simplifies this by providing immediate insights into plant health without the need for post-processing. Traditionally, a major drawback of multispectral sensors was the time-consuming post-processing needed to extract useful information. Creating an NDVI map requires images with sufficient overlap and resolution (GSD) to ensure accuracy (Davis et al. 2022). This is especially important in areas like wetlands, where the landscape often has uniform textures and complex shapes, making image analysis more challenging (Pix4D 2024).

The NDVI video is depicted in real time to the drone operator and user of information, in this case a stakeholder (e.g., cattle rancher, biologist, ecotourist guide). This real-time delivery of information can enhance comprehension of the environmental conditions and increase user engagement (Lv et al. 2022). When an area of interest is found, it is quick and simple to switch between live NDVI and RGB video using the hand controller. Cycling between live sensor modes presents two sets of images for the same area. The drone operator and stakeholder can analyze each image scene while qualitatively applying elements of aerial image interpretation, to include size, shape, shadow, tone, color, texture, pattern, height, and depth (Aber et al. 2019). Stakeholders can play a vital role by directing the UAS to designated areas of interest. The UAS operator can record video and still images affording opportunities for post hoc analysis and sharing.

Utility of Data Collected

Using UAS (drones) for remote sensing in environmentally important areas offers multiple benefits to stakeholders. It creates opportunities for collaboration among diverse groups, including residents, academic institutions, NGOs, government agencies, and others. These multidisciplinary teams—often with international representation—bring a wide range of perspectives and expertise, leading to outcomes greater than what any one group could achieve alone.

In the Iberá Wetlands service-learning project, local stakeholders gained access to processed environmental data for future planning and research. This data supports the use of advanced UAS technologies and provides timely spatial information. Additionally, by sharing data internationally—through live streams (e.g., with the Brevard Zoo) or academic outputs—the project helps raise global awareness of the Iberá Wetlands and showcases Argentina's success in wetland and biodiversity restoration.

The data collected, processed, and shared from the Iberá Wetlands helps to further validate UAS as a cost-efficient, high-resolution means for monitoring while simultaneously increasing the extent of spatial coverage, resolution, and timeliness of monitoring. UAS have the potential to effectively monitor wetlands on short temporal scales and as fast as real time. RGB images, and the derived orthomosaic image, truly provide a remarkable level of detail as evidenced by the GSD of .83 cm. This level of detail allows experts to review images and identify specific plants, by type, using highly accurate colorization details. The resolution of UAS imagery allows for accurate classification of plant life in wetlands and associated habitats. The flight altitude of 29 meters ATO was selected with the aim of gathering ultra-high-resolution images. This level of detail is sufficient for experts to examine imagery and conduct classification of plants if desired. Previous work conducted by NOAA (Davis et al. 2022) corroborates this assessment.

Photogrammetric techniques do have limitations in geometrically complex and vegetatively dense locations like wetlands. The challenge remains to choose a GSD that provides a level of detail that is necessary to meet the needs as identified for the specific project by the stakeholders. Over extremely uniform areas (i.e., covered with geometrically similar vegetation and water surfaces) imagery with a GSD greater than 10 cm will be necessary for stitching mosaics. This is confirmed by guidelines published for SfM processing (Pix4D 2024).

Live RGB video and real-time NDVI video are not constrained by the challenges of stitching during post processing. The live techniques can provide extremely detailed imagery in real time and be recorded. However, as stated, the live imagery with its oblique viewing angles provides the viewer with a picture that is set in context with the surrounding environment due to slanting perspectives (Figures 10 and 11). Photogrammetrically derived orthomosaic images, with planar perspectives and nadir examination angles, create a comprehensible 2D map perspective. Examining wetland areas using a combination of oblique live viewing areas and planar orthomosaic maps provide a high level of detail. This combination of approaches to remote sensing was very helpful while examining the cattle ranch. The technique also worked in the natural wetland areas of Puerto Galarza. However, levels of detail were lower here for the planar orthomosaic image.

The Iberá Wetlands serves as one use case for UAS remote sensing. Each wetland has unique characteristics that need to be addressed. The decision to use real-time imagery, postprocessed imagery, or a combination of the two is a function of user needs, time, and resources.

Figure 14. Ecotourism in Iberá Wetlands kayaking (left) and horseback tours (right).

Figure 15. Wildlife in the Iberá Wetlands caiman (left) and fly catcher (right).

Figure 16. Ecotourism journey on horseback through the Iberá Wetlands.

CONCLUSIONS

The collection of UAS remotely sensed data, obtained during service learning, demonstrated an effective means for assessing vegetative health in the Iberá Wetlands. This occurred from both post-processed and real-time perspectives. The post-processed NDVI index maps, orthomosaic maps, and recorded live video afforded opportunities to examine images, discuss findings in detail, and share data. The live RGB and NDVI imagery provided a real-time means of interacting with stakeholders, affording a high degree of cognitive connection between what is seen in the real world with human eyes and what is seen through the aerial perspective from the drone's camera. Insights gained here help validate the ability of UAS to remotely sense wetland environments to help concerned stakeholders understand the true state of vegetation. Integrating UAS-based remote sensing operations over wetlands into service-learning initiatives enriches academic curricula by exposing students and stakeholders to advanced methods for assessing vegetative health and ecosystem dynamics through real-time, data-driven analysis.

Although the Iberá Wetlands once experienced severe environmental degradation—marked by the loss of large wildlife, reduced water flow, and declining biodiversity—visitors today witness a thriving, biologically rich ecosystem. This transformation reflects a large-scale restoration initiative aligned with the UN Sustainable Development Goal for Life on Land. Intensive conservation efforts by both private and government organizations have successfully restored the region, promoted sustainable use, and increased biodiversity. At the study sites, the wetlands were vibrant with native vegetation and abundant wildlife.

Upon close inspection, from the aerial perspective afforded by UAS, the environment appeared healthy. The mixed-use site showed clear signs of human-related activities that included cultivation, grazing cattle, and horses. The mixed-use site is embedded into the wetlands. The immediate areas in the surrounding terrain were packed with dense wetland vegetation and associated animal life. The natural wetlands site at Puerto Galarza demonstrated the effectiveness of preservation in a purely natural state environment. There was no evidence of human presence other than ecotourist. The site was home to a large population of caimans and capybaras in their natural habitat and offered visitors the opportunity to explore the area via nature trails, kayaking, and guided boat tours. Overall, the chosen sites were representative of the two main use cases of land and water in the Iberá Wetlands and provided a sample to assess the effects of conservation strategies in the region. Despite numerous setbacks from natural and human activities, the Iberá Wetlands have rebounded and are thriving once more. The data collected, in the form of visible light and multispectral imaging, with subsequent inspection and consultation with local stakeholders, demonstrated a significant increase in the region's health and the positive effects of conservation programs. The return of the region to its original state, where the wetlands are a functioning component of the ecosystem within Argentina, aligns with the UN Sustainable Development Goal 15 Life on Land.

AUTHOR DECLARATION

This is an original work that has not been previously published. Citations are given for quotations from published sources. Sources for all images are also given in figure legends.

REFERENCES

Aber, J.S., I. Marzolff, J.B. Ries, and S.E.W. Aber. 2019. *Small-Format Aerial Photography and UAS Imagery*. Second Edition. Elsevier. doi: 10.1016/C2016-0-03506-4.

Aceves, R.I. and P.A. Aceves. 2008. Preparing Aviators for the 21st Century: A 3-Year Case Study of Service Learning in the Aviation Classroom. *Collegiate Aviation Review International* 26(1). doi: 10.22488/okstate.18.100362.

Allen, D. 2023. *The Iberá Wetlands: Argentina's Answer to Yellowstone*. https://www.bbc.com/travel/article/20230614-the-iber-wetlands-argentinas-answer-to-yellowstone

Astin, A. and L. Sax. 1998. How Undergraduates Are Affected by Service Participation. *Journal of College Student Development* 39.

Bettencourt, M. 2015. Supporting Student Learning Outcomes Through Service Learning. *Foreign Language Annals* 48(3), pp. 473–490. doi: 10.1111/flan.12147.

Bevington, A., H. Gleason, X. Giroux-Bougard, and T. de Jong. 2018. A Review of Free Optical Satellite Imagery for Watershed-Scale Landscape Analysis. *Confluence: Journal of Watershed Science and Management* 2. doi: 10.22230/jwsm.2018v2n2a18.

Cannizzaro, J.P. et al. 2019. Remote detection of cyanobacteria blooms in an optically shallow subtropical lagoonal estuary using MODIS data. *Remote Sensing of Environment* 231, p. 111227. doi: 10.1016/j.rse.2019.111227.

Caspersz, D. and D. Olaru. 2017. The value of service-learning: the student perspective. *Studies in Higher Education* 42(4), pp. 685–700. https://doi.org/10.1080/03075079.2015.1070818.

Cassidy, E. 2023. *Fires Burn in Argentina's Iberá National Park*. https://earthobservatory.nasa.gov/images/151011/fires-burn-in-argentinas-ibera-national-park.

Davis, J., R. Giannelli, C. Falvo, B. Puckett, J. Ridge, and E. Smith, E. 2022. Best practices for incorporating UAS image collection into wetland monitoring efforts: a guide for entry level users.

DJI. 2024. *DJI Mavic 3M User Manual*. 1.0. DJI. https://ag.dji.com/mavic-3-m/specs.

Esri. 2023. ArcGIS Pro 3.1.0.

Esri. 2024. *Data Classification Methods*. https://pro.arcgis.com/en/pro-app/latest/help/mapping/layer-properties/data-classification-methods.htm.

Gebert, G., L. Griffin, J. Lawlor, L. Davis, K. Vander Velde, and S. Ali. 2019. Advanced Photogrammetric Modeling of Dranoc Kullas Using Small Unmanned Aircraft Systems. https://commons.erau.edu/student-works/144.

Jensen, J.R. 2007. *Remote Sensing of the Environment*. Upper Saddle River, NJ: Prentice Hall.

Jeziorska, J. 2019. UAS for Wetland Mapping and Hydrological Modeling. *Remote Sensing* 11(17), p. 1997. doi: 10.3390/rs11171997.

López, M. 2022. *Iberá Project*. https://www.rewildingargentina.org/Iberá-project/.

Lv, J., C. Cao, Q. Xu, L., Ni, X. Shao, and Y. Shi. 2022. How Live Streaming Interactions and Their Visual Stimuli Affect Users' Sustained Engagement Behaviour—A Comparative Experiment Using Live and Virtual Live Streaming. *Sustainability* 14(14), p. 8907. doi: 10.3390/su14148907.

Macchiarella, N.D., J. Robbins, and D. Cashdollar. 2019a. Rapid Virtual Object Development using Photogrammetric Imagery Obtained with Small Unmanned Aircraft Systems -Applications for Disaster Assessment and Cultural Heritage Preservation. *AIAA SciTech 2019 Forum*. Reston, Virginia: American Institute of Aeronautics and Astronautics. doi: 10.2514/6.2019-1974.

Macchiarella, S., R. McGinnis, K. Thaci, and N. Macchiarella,. 2019b. Cultural Heritage Preservation Through Service Learning: Applying Unmanned Technologies in the Balkans Bridging Technical and Social Science. *CIEE Annual Conference*. New York, New York.

Pappalardo, S. E. and D. Andrade. 2022. Drones for Good: UAS Applications in Agroecology and Organic Farming. 1st ed. CRC Press, pp. 122–148. doi: 10.1201/9780429052842-8.

Pettersson, H.L. and S.H.C. de Carvalho. 2021. Rewilding and gazetting the Iberá National Park: Using an asset approach to evaluate project success. *Conservation Science and Practice* 3(5). doi: 10.1111/csp2.258.

Pix4D. 2024a. Pix4Dmapper Pro.

Pix4D. 2024. *How to Improve the Outputs of Dense Vegetation Areas Using PIX4Dmapper?*

Pokrzywinski, K., R. Johansen, M. Reif, S. Bourne, S., Hammond, and B. Fernando. 2022. Remote sensing of the cyanobacteria life cycle: A mesocosm temporal assessment of a Microcystis sp. bloom using coincident unmanned aircraft system (UAS) hyperspectral imagery and ground sampling efforts. *Harmful Algae* 117, p. 102268. doi: 10.1016/j.hal.2022.102268.no

United Nations Environment Programme. 2015. *UNEP and the Sustainable Development Goals*. https://www.unep.org/explore-topics/sustainable-development-goals.

Weier, J. and D. Herring. 2000. *Measuring Vegetation (NDVI & EVI)*. https://earthobservatory.nasa.gov/features/MeasuringVegetation.