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Observing Our Natural World with Drones

A Collection of Learning Lessons for Middle and High School Educators

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Virginia Cooperative Extension
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EXPERT REVIEWED

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Disclaimer

Drone operations carry some inherent risk. We have provided several safety tips and suggestions to help mitigate that risk. Remote pilots in command (RPIC) should always follow all federal, state, and local regulations during flight operations. We also recommend following all manufacturer's recommendations and maintenance schedules for equipment. All information presented in this manual is intended for educational and informational purposes. It is not a substitute for legal or other professional advice. All exercises, learning lessons, flight operations, fieldwork, and associated missions are conducted at your own risk.

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Access

This educational resource (and a broader collection of educational resources) is available either as a hard copy or ePublication through GeoTEd-UAS and Virginia Cooperative Extension on the Virginia View website (https://virginiaview.cnre.vt.edu/tutorials/).

For additional information or inquiries, please contact John McGee at jmcg@vt.edu.

Foreword

The proliferation of autonomous aircraft for commercial applications is a relatively new phenomenon. Not only is the commercialization of small uncrewed aircraft systems (sUAS, also known as drones) new, but this technology was brought to market very quickly. It was as though a threshold event took place – drones just started appearing everywhere. For example, I remember noticing my first drone while shopping at a technology-based box store. That same week, I was grocery shopping in my neighborhood grocery store and couldn't help but notice a collection of drones on the shelf in the "gadget" section. Later, I found a stack of drones (though the toy variety) sitting by the ice cream freezer at my rural neighborhood's gas station. It was then that I realized that something big was happening.

Drones are not just here to stay as recreational toys, but they are quickly transforming many different businesses by serving as efficient data collection vehicles. Drones are also poised to provide transportation (package delivery), search and rescue, and a multitude of other application needs.

What led to the rapid and widespread dissemination of this autonomous technology? Obviously, the military has been using drone technology for decades. However, the actual commercialization of drones is closely tied to the technology that we have been carrying around in our pockets each day – our smartphones. Smartphones miniaturized and integrated many of the core components of drones. Smartphone technology spurred the development of more powerful and compact batteries, CPUs, gimbals, compact high-resolution cameras, global navigation satellite system (GNSS) receivers, and electronic compasses. All these components on their own represent what I consider to be miracles of technology. However, the intricate and embedded software is what ensures these components are fully integrated. Thus, the evolution of the commercial drone industry has its roots in many hardware and software technologies, including the smartphone.

Since their initial development, the commercial application of uncrewed systems (which includes airborne, terrestrial, and aquatic) in our society can be described as nothing short of phenomenal. These transformative technologies are changing the way that we understand, monitor, and manage our natural environment, and plan, construct, and inspect structures and communities. These systems are still in their infant stages of development. While the impacts associated with these vehicles are impressive, I suspect that very few individuals understand the true influence that these systems will have on our communities in the future. Beach (2017) suggests that the overall drone market could be as revolutionary as the internet, as new markets, services, and applications are more fully realized.

How could this be? When most individuals think about "drones," they may limit their consideration to "just the drone." But a drone is just a vehicle. The value-added component of any vehicle is the payload. Drones can carry an array of payloads, including sensors, packages (for delivery), and other inputs (to use in agriculture, for example). Many of the applications that are included in the following exercises are associated with sensor payloads.

Drones provide "eyes in the sky" and a unique perspective to quickly and efficiently collect data. This perspective is augmented by the fact that many of the payload sensors that the vehicle can carry were developed to collect data (information) that is located outside of the human visible spectrum. Thus, drones provide us with the ability to collect data quickly, from an elevated perspective, at an unusually high resolution. This data is captured from both within and beyond the human visible spectrum. So, the buzz about drones is not really about the drone. It is about the information that the drone can collect to help us better understand our world and make informed decisions.

While there will certainly be increased demand for drone operators in the future, the true value-added employment opportunities are associated with the collection and interpretation of all this data that is being collected. We will require additional programmers to help develop and guide machine learning and artificial intelligence to support the processing of images. There will be increased demand for individuals to generate more precise, more powerful, and more diverse ranges of sensors that will be able to observe our communities in new ways. In addition to specialists, we will need to cultivate generalists who can integrate data components from an array of disciplines to make informed decisions. And there will always be a need for individuals who can take this highly technical information and parse it to create digestible knowledge that can be communicated effectively.

The common denominator for all of this is education. I believe, and there are many others who share my opinion, that we are still in the "rotary phone age" of drone and sensor implementation. With that being said, the regulatory environment and technological opportunities are likely to continue transforming rapidly. This poses both a tremendous challenge and an opportunity for our educational system, for educators, and for students.

A new era in Earth observation and understanding is underway. If utilized correctly, this data will inform better science and will guide decisions and policies from the local to national levels. This is why drone enthusiasts often claim that "Looking down is looking up!" The technology is rapidly evolving, gaining acceptance and is increasingly being utilized. As educators, it is our responsibility to ensure that students gain the opportunity to interact with these tools early so that they can be in a position to be the drivers of change in the future.

Keep looking down!

– John McGee

Reference

Beach, R. P., Stouffer, V. L., Belcher, G. J., & Schultz, P. M. (2017, March). *Commonwealth of Virginia Unmanned Aerial Systems Strategic Economic Development Plan* (CIT60T1, Revision 1). LMI.

Getting Started

It is often stated that every flight operation is unique and different, since there are an infinite number of parameters that can impact a flight. These include environmental conditions (such as weather, landscapes, and wildlife); cultural and social issues (including other individuals or structures present in the area); sUAS (drone) project personnel (we all have our good days and bad days); and drone software issues and hardware performance. The Getting Started section of this manual provides an overview of safety considerations and drone rules and regulations, along with an example of a checklist for drone operations. These documents are not intended to provide a complete list of precautions to consider prior to every flight; however, they provide a starting point for your flight operations. With additional experience, you can expand on these documents.

Overview: Drone Rules and Regulations

Disclaimer: Please follow all local, state, and federal regulations for sUAS aircraft operations. In addition, you are advised to consult with the administration of your facility to ensure all policies and procedures are followed. The following information is provided as suggested guidance. This information is not intended to be your only source for rules and regulations. For up-to-date Federal Aviation Administration (FAA) regulations, see the FAA website (https://www.faa.gov/uas/), as rules and regulations frequently change. Questions, clarifications, and interpretations concerning regulations should be directed to the FAA.

Certificates and Registration

- All drone pilots should obtain their Remote Pilot Certificate (RPC, aka FAA Part 107 certificate) or be under the direct supervision of a certificated pilot when operating a drone.
- The remote pilot in command (RPIC) will have all decision-making responsibilities during the flight.
    - The RPIC has the final authority and direct responsibility for the safe operation of the drone.
    - The RPIC should contact risk management or other authority before conducting flights on school grounds.
- All aircraft weighing more than 0.55 pounds should be registered with the FAA and the registration number should be placed on the aircraft. See “FAA DroneZone” below for information on registering your drone.

Operating Requirements

- If operating within 30 minutes of morning or evening civil twilight, the aircraft must have an anti-collision light that is visible for at least 3 statute miles.
- Any equipment attached to the aircraft must be secure and not impact the flight performance (e.g., balance). All aircraft should be less than 55 pounds at takeoff.
- Airspace
    - Drone flights are only allowed in Class G (unregulated) airspace. Please check Sectional Aeronautical Charts to ensure you will be flying in Class G airspace.
    - The maximum allowable altitude is 400 feet above ground level (AGL), and the maximum aircraft speed is 100 mph.
    - You should check for Notices to Air Missions (NOTAMs) and Temporary Flight Restrictions (TFRs) during flight planning and before takeoff. A few good sources are the FAA website (https://www.faa.gov/uas/), SkyVector Aeronautical Charts website (http://www.skyvector.com/), and the Flight Service website (http://www.1800wxbrief.com/).

- The pilot must always maintain visual line of sight while operating the drone. The use of visual observers (VOs) as part of a flight plan is beneficial, but a pilot or an observer can only be responsible for one aircraft at a time. Observation must be unaided (no binoculars).

- Be aware that the Virginia High School League (VHSL) has issued a Temporary Flight Restriction for all sporting events.

FAA DroneZone

- Create an account with the FAA DroneZone on the FAA website (https://faadronezone.faa.gov) to register your drone(s), request a waiver, and/or report an accident.

- Accident reporting (responsibility of the RPIC).

    - Report drone accidents that involve serious injury, loss of consciousness, or property damage of at least $500 to the FAA within 10 days.

    - Part 107 Accident Reports can be submitted and reviewed through your FAA DroneZone account.

- FAA Waivers

    - The FAA can issue waivers to certain requirements of Part 107 when operators demonstrate they can fly safely under the waiver without endangering other aircraft, people or property on the ground or in the air.

    - Some examples are flying at night, beyond visual line of sight, or over people. For more information visit the FAA website (https://www.faa.gov/uas/commercial_operators/part_107_waivers/).

    - Part 107 Waivers/Authorizations can be created and managed through your DroneZone account.

Drone Safety

Disclaimer: Please follow all local, state, and federal regulations for drone operations. Consult with the administration of your facility (school or other entity) to ensure all policies are followed. The following information is provided as a set of recommendations and is not meant to be your only source of safety guidance.

Before Flight

Complete a Preflight Checklist

You should follow all manufacturer recommendations before powering on the drone. An example checklist for the DJI Mavic is provided after this section, but manufacturer recommendations always take precedence. Items to inspect typically include:

- Propellers – Ensure there are no nicks, cracks, or bends.
    - Damaged propellers should never be flown. Never attempt to repair propellers.
    - Carbon fiber propellers should never be used when flying with students unless a specific mission would require their use. Carbon fiber propellers can cause serious injuries during an accident.
- Battery – Ensure the battery is fully charged and not damaged.
    - Ensure the battery is not swollen or hot.
- Equipment installations – Ensure all equipment is securely attached.
    - Check propellers to ensure they are securely and properly attached.
    - Check the battery to ensure is it properly attached.
    - Secure all panels, doors, or other latching devices.
    - Check gimbal and camera to ensure they are securely attached.
- Check the aircraft airframe for obvious defects.
    - Be sure the landing gear is secure and straight.
    - Ensure there are no cracks in the airframe.
    - Check to see that all lights are working.
    - If installed, make sure the anti-collision lights are functional.
- Transmitter/controller – Make sure they are functioning.
    - Ensure batteries are fully charged.
    - Ensure software is updated.

Clear the Operational and Flight Areas

- Be sure the operational area is safe and clear.
    - Ensure that the RPIC as well as any other flight crew (such as visual observers, or VOs), are in an area where they will not be disturbed or distracted.
    - Consider using flags, cones, and/or caution tape to designate a crew area with a buffer to prevent people from entering the area of operation or distracting crew members.
    - Ensure your flight will not travel over people unless they are crew members or an FAA waiver has been obtained.
- Check current and future weather conditions.
    - Ensure at least 3 statute miles of visibility.

    - Maximum flight altitude is at least 500 feet below clouds.
    - Flight pattern is at least 2,000 feet horizontally from clouds.
    - Print the most recent METAR (Meteorological Aerodrome Report) for your records.
    - Determine if temperatures could be lower than 40 degrees Fahrenheit, which will impact battery performance.
    - Assess the chance for icing at any flight altitude.
- Ensure that you are clear to operate in the airspace.
    - Ensure that you are operating in Class G airspace.
        - If not, acquire a Low Altitude Authorization and Notification Capability (LAANC) through one of the FAA-approved LAANC UAS service providers on the FAA website (https://www.faa.gov/uas/programs_partnerships/data_exchange/#approved) or a apply for a waiver on the FAA website (https://www.faa.gov/uas/commercial_operators/part_107_waivers/).
    - Check for Notices to Air Missions (NOTAMs) on the NOTAM website (https://notams.aim.faa.gov/notamSearch/nsapp.html#/).
    - Acquire permission from owner if operating over private property.
    - Check for restrictions over public lands.
    - If operating a DJI, check the GeoZone Map on the DJI website (https://www.dji.com/flysafe/geo-map).

Drone Flight Operations

Indoor Environment

Flying indoors can present different challenges than flying outside. In addition to following all safety recommendations, please be especially mindful of the following circumstances when flying indoors.

- Be sure the operational area is safe and clear.
    - Aircraft flight and operational areas need to be kept clear. This can be challenging in a small indoor environment. Make sure to have signage and markers to keep curious observers at a safe distance away from flight areas and operational areas.
    - Walk and scan the flight area before the flight to note any potential safety hazards. Sprinkler nozzles and fire detection equipment can be especially problematic for indoor drone flights.
- Check communications.
    - Commercial and educational buildings may have strong Wi-Fi signals. These signals can potentially interfere with the communication between the transmitter and the aircraft. Many aircraft and transmitters use a 2.4 GHz frequency that is the same as Wi-Fi. If available, use a frequency spectrum analyzer to determine potential interference before a flight.

Outdoor Environment

- Be sure the operational area is safe and clear.
    - Many of your missions will focus on natural resources. Therefore, situational awareness will be critical for a safe flight.
    - Walk the flight area before the flight to note any potential safety hazards. Trees and other tall vegetation could create obstructions during your flight. Please note the height of these structures.
    - If your flight path proceeds between tall trees or buildings, please be especially aware of increased wind velocities between these structures.
    - Always maintain visual line of sight (VLOS) of your drone and adhere to other federal and local regulations.
    - Wildlife can create hazards during the flight, but it's important not to impact wildlife negatively during your missions, and it may be illegal to do so. Many species of birds could be territorial or inquisitive. Swallows

and martins will often fly near drones. Mockingbirds, crows, and birds of prey could approach or dive at your drone. Please be cautious and change your flight direction if necessary to avoid potential conflicts.

Safety When Not in Flight

- Secure all equipment when not in flight.
- Safely store LiPo (lithium polymer) batteries.
    - Store at levels and temperatures recommended by the manufacturer.
    - Use LiPo bags.

Notes:

Example Flight Checklist for the DJI MAVIC

Before you walk out the door:

- [ ] Check to make sure that you are flying in a safe flight zone.
    - Verify your flight is in Class G airspace by checking the SkyVector website, (https://www.skyvector.com), or the smartphone app B4UFLy.
    - Check flight services on the Flight Service website (https://www.1800wxbrief.com/) for:
        - TFRs.
        - NOTAMs.
        - METAR.
- [ ] Check DJI's GeoZone map (https://www.dji.com/flysafe/geo-map) to see if the drone requires unlocking.
- [ ] Check weather conditions, wind, temperature, etc.
- [ ] Check for firmware updates.
- [ ] Check for DJI GO 4 app updates.
- [ ] Flight planning:
    - Plan flight route.
    - Review manual flight procedures.
- [ ] Make sure area is free of obstacles such as tall trees or power lines. Scout in Google Earth or other visual mapping software.
- [ ] Confirm all items are fully charged:
    - Drone batteries.
    - Controller.
    - Tablet/cell phone.
- [ ] Erase data from the micro SD card.
- [ ] Inspect:
    - Overall aircraft/props/motors for damage.
    - Battery for damage.

Supply list

- [ ] Remote Pilot Certificate(s).
- [ ] Mavic Pro drone.
- [ ] Takeoff/landing pad.
- [ ] Batteries.
- [ ] Remote controller (RC).
- [ ] Extra propellers.
- [ ] Micro SD card.
- [ ] Phone or tablet with the DJI GO 4 app.
- [ ] Cable to connect RC to phone.
- [ ] First aid kit
- [ ] Fire extinguisher

Prepare the aircraft

- [ ] Unfold the propeller arms.
- [ ] Extend the propellers.
- [ ] Remove camera/gimbal covers.
- [ ] Attach camera filter (optional).
- [ ] Insert the micro SD card.
- [ ] Unfold the controller antennae.
- [ ] On the side of the RC, make sure "Sport" mode is off.
- [ ] On the Mavic Pro, make sure the mode switch is set to "RC."
- [ ] Set Mavic Pro on a flat, level surface.

- [ ] If using a phone, attach to the RC.
- [ ] If using a tablet, attach the tablet and tablet adapter to the RC.
- [ ] Make sure your team has been briefed about the project.

Powering up

- [ ] Turn on the phone / tablet and enter the DJI GO 4 app.
- [ ] Turn on the remote controller (before turning on the drone).
- [ ] Turn on the Mavic Pro.
    - Lights will flash on the Mavic Pro.
    - The Mavic Pro will make the “DJI beep-beep” sound.
    - The gimbal will move.
- [ ] Connect Mavic Pro to DJI GO 4.
- [ ] Adjust camera settings.
- [ ] Wait for GPS and compass.
- [ ] Calibrate the drone if needed.
- [ ] Establish the return to home point.
    - Check “READY TO GO GPS” in upper left of controller.
        - Check minimum “Return to Home Altitude” setting, taking into consideration nearby trees, structures, and power lines.

Begin flight

- [ ] Hold both sticks down to the middle-center.
- [ ] Let the Mavic Pro idle and inspect for irregular vibrations or movements.
- [ ] To launch the Mavic Pro, move the left stick forward and the Mavic will launch.
- [ ] Hover the drone to check for irregular vibrations/movements/sounds.
- [ ] Fly your mission.
- [ ] To land/stop the Mavic Pro, hold the left stick down until the drone lands and the propellers stop.

Post flight

- [ ] Turn off the drone (battery) first.
- [ ] Turn off the controller (after turning off the drone).
- [ ] Inspect the drone/batteries/propellers and record anomalies.
- [ ] Record battery usage in the battery log.
- [ ] Document appropriately in the flight log.

Notes:

Learning Lessons

Natural resource managers may be in charge of managing an array of resources that can include land, water, plants, animals (ranging in size from a mosquito to a whale!), soils, and air quality. Natural resource professionals across Virginia are facing important issues including the management of coasts, streams, lakes, and other water resources, forests resources, grasslands, fields, wetlands, invasive species, endangered species, air quality, erosion, and wildlife. Drones, and the payloads (cameras) that they carry, are increasingly being used to help these professionals to monitor and steward Virginia's natural resources efficiently and effectively. The activities in this manual are designed to help build capabilities of young people interested in learning more about how drone technology can help shape a brighter future and support Virginia's natural resources. Each of these exercises can be expanded upon, and the applications highlighted in this manual are far from a complete list.

Using drones to support natural resource applications often spans across disciplines, and the benefits from one discipline can impact other disciplines. For example, drones serve as an important tool for farmers who are the practicing precision agriculture. Using information collected from sensors (cameras) on drones, farmers can minimize the amount of fertilizers, pesticides, herbicides and other inputs they apply on their fields while maximizing crop production. This type of practice can result as a win-win for the farmer (lower production costs and profits), the environment (fewer inputs and less runoff), and the consumer (lower food costs). Thus, the use of drones in farming can also have positive benefits on natural resources.

The following activities build on each other, starting with practicing basic drone flight skills and expanding to using software for analysis and comparing results using traditional techniques with those using drone technology. References, websites, and supplemental information is provided at the end of the exercises, and a glossary is included at the end of the manual. By expanding the knowledge base of those using this manual, we hope to make a lasting impact on the future of the commonwealth, since it is anticipated that drones will be a vital component of Virginia's future economy.

Notes:

Activity 1: Drone Flight Practice

Providing students with an opportunity to practice flight skills in a controlled environment builds their capabilities and provides them with initial experience. This will enable them to become better pilots when they later operate in regulated airspace. Operating flights and practicing maneuvers in an uncontrolled environment will further strengthen students' flight skills. Also keep in mind that there is a separate document that provides an assortment of manual flight exercises. This is available on the Virginia View website (https://virginiaview.cnre.vt.edu/tutorials/).

Goal and Objectives

Goal

Students will learn to maneuver around obstacles and improve reaction time during flight operations through practice with various activities in controlled environments.

Objectives

Students will improve their flight skills by completing at least one of the following activities in a controlled environment:

1. Practice controls using a flight simulator.

2. Practice controlling a drone by maneuvering through an obstacle course.

3. Practice remote, or "beyond visual line of sight" (BVLOS), flight operations. Note that this is currently not approved by the FAA without a waiver, but BVLOS can be conducted in a controlled environment for short amounts of time. Refer to FAA regulations.

    a. The original FAA 'drone' regulation document (Part 107) is available from the FAA website (https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_107-2.pdf)

    b. A more concise updated webpage associated with FAA Drone regulations and other relevant information is available on the FAA website (https://www.faa.gov/uas)

4. Practice controlled delivery of a payload.

5. Some drones (and controllers) have different capabilities. Practice flying different drones with various flight capabilities, including altitude hold, object avoidance sensors, and First Person View (FPV). Complete any of the above activities while incorporating these additional equipment challenges:

    a. Operate a drone with altitude hold attributes:

        i. With many of these drones, the left joystick "snaps" back to the zero position (centered) when it is released.

        ii. Potential drone platform examples: mini drone build set, most DJI products.

    b. Operate a drone without altitude hold attributes:

        i. With many of these drones, the left joystick does not "snap" back to the zero position (as noted above). Instead, the joystick stays where it is when you remove pressure (custom controllers like the FrSky will not "snap" but can be set up with and without altitude hold).

        ii. Potential drone platform examples: Cheerwing, SYMA.

    c. First Person View requires additional hardware (typically requires goggles) for the pilot to watch through the camera during flight. Some FPV equipment allows the RPIC to keep visual line of sight with the drone, but most do not. This should be done in a controlled environment.

Flight Simulators

Materials

- Personal computer.
- Remote control (requirements vary based on software).
- Simulator software such as:
    - DJI Flight Simulator (https://www.dji.com/simulator) (graphics intensive).
        - Uses the actual remote control from DJI products.
        - Some features required a paid version.
    - FPV Freerider (https://fpv-freerider.itch.io/fpv-freerider).
        - Uses an external remote control such as FrSky or GoolRC.
        - Some features required a paid version.
    - Crazy Games Drone Simulator (https://www.crazygames.com/game/drone-simulator).
        - Works in any web browser (although some school web filters block the site).
        - Uses a keyboard for the flight joystick.

Overview

This activity gives students an opportunity to practice with their remote controllers before using a drone. The challenges and activities in the simulator software can be set with varying levels of difficulty. The software's requirements of levels achieved and unlocked is a good way to mark progress.

Controlling a Quadcopter by Maneuvering an Obstacle Course

Materials

- Microdrone(s) (approximately 100-200 millimeter diagonal frame size).
- Obstacle course:
    - Homemade (hula hoop, pool noodles, PVC pipe, tape, etc.).
    - Store purchased (Amazon, Newegg, Walmart, etc.).
    - Combination of both.

Overview

Be creative in how you set up your drone obstacle course. Your goal is to practice in a controlled environment. Starting indoors with a small- to medium-sized drone is the most appropriate way to begin. Set up your course with boundaries (painters tape works well) and establish goals that require the drone to maneuver up, down, left, and right. You can also add in some bonus points for flipping and stunts.

Challenge

There are various ways to challenge students with this activity. Award points in the following areas of flight:

1. **Time from the start of the motors to successful landing.** Note that if too much emphasis is placed on time, pilots will figure out that they can just take off and then land. Use a range of 0-3 minutes = high points; 3.01-5 minutes = medium points; more than 5.01 minutes = low points.
2. **Completion of each stage of the course.** Apply optional bonus points for stunts as desired.
3. **Staying in bounds.** Apply penalty points for flying out of bounds (or you can apply an automatic disqualification if they go out of bounds).
4. **Landing target bonus** (fig. 1):
    a. Highest points: Land completely inside the target circle.

b. Medium points: Land primarily but not completely inside the target circle.

c. Low points: Land with the majority of the drone off the target circle.

d. No points: Land completely off the target.

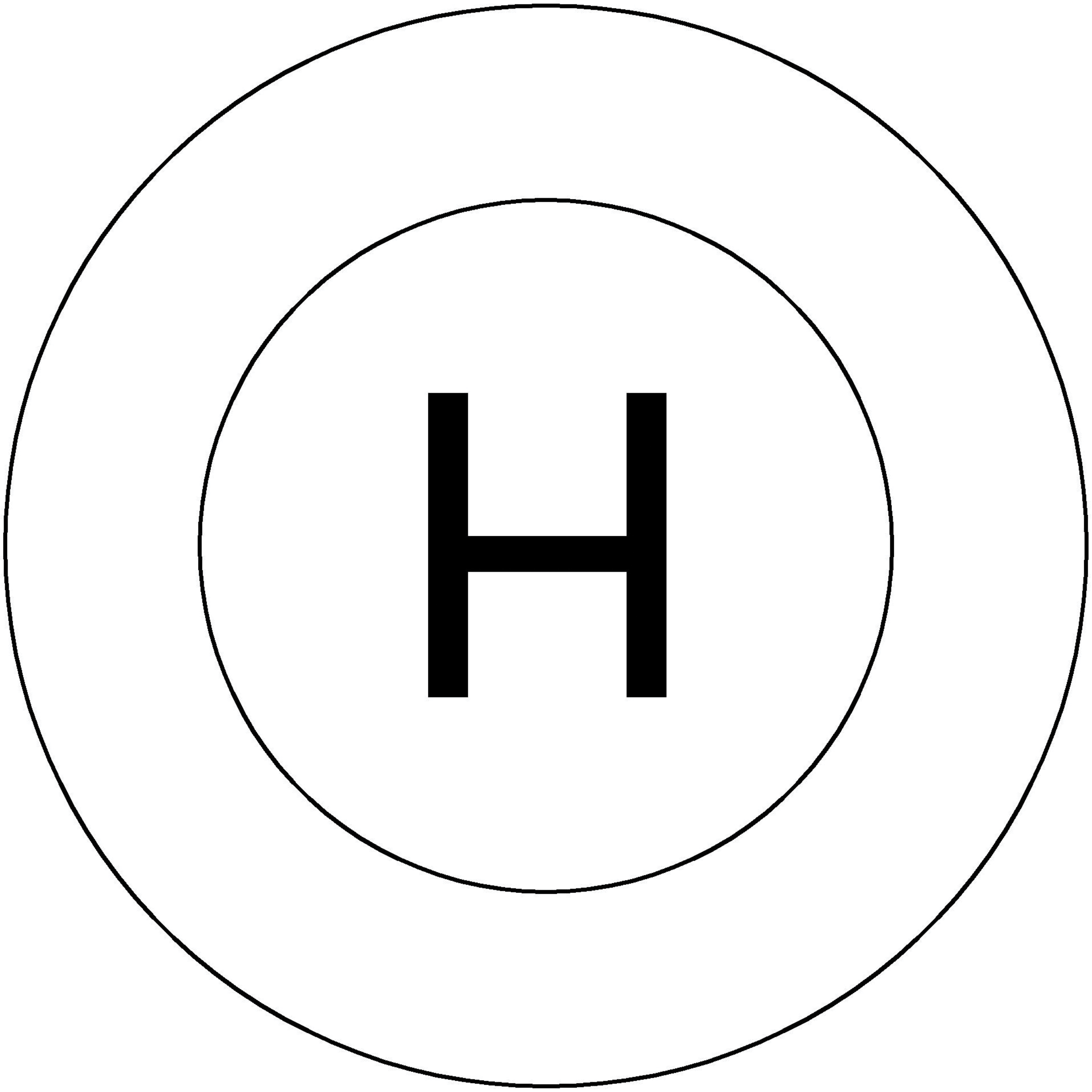


Figure 1: Landing target.

Prize Suggestions

- Bragging rights (classroom plaque displaying their name, certificate etc.)
- Extra credit points.
- Drone kit.

Remote Operations and Beyond Visual Line of Sight (BVLOS)

Materials

- Microdrone(s) (approximately 100-200 millimeter diagonal frame size).
- Screen divider, such as:
    - Partition wall.
    - Green screen.
    - Foam tri-fold poster board.
- Personal computer or video monitor.
- Webcam (detached from the computer).

Overview

There are times drones may need to be controlled beyond the operator's line of sight. An extreme example of this is the rover units that are sent to explore other planets. While flying drones beyond a visual line of sight is not currently allowed in FAA airspace, it is a fun and challenging exercise in a controlled environment for even the most experienced drone operator.

Challenge

This activity can be set up with a much smaller boundary and much simpler obstacles than the last session. In fact, it may be best to start by having the operator take off, fly over or under an obstacle, and land on an established target.

1. Set up an obstacle table that has a takeoff point, obstacle, and a landing target (you can simply use tape for the takeoff and landing spots).

2. Place a screen between the drone operator and the obstacle table so that the operator cannot see the obstacle table.

3. Arrange the webcam to point toward the obstacle table, and have it attached to a PC or video monitor that is positioned where the drone operator can see the video feed.

4. Using only the video feed, have the drone operator fly the drone and complete the mission using only the video feed.

You can incorporate some of the judging criteria from the obstacle course into this activity if you have very successful drone operators.

Notes:

Payload Delivery

Materials

- Drone with more than 10 grams payload capability (you may need to remove existing camera payload for this activity). Examples include:
    - DJI Phantom II, III, IV.
    - DJI Mavic Air (be aware of collision detection and payload placement).
    - DJI Spark.
- Drone clip or similar mechanism (fig. 2).

Overview

Drone package delivery is a rapidly growing industry. This is a great group activity because the flight team will need spotters and someone to release the mechanism. Students will learn about prop wash, battery life, payload capabilities, trajectory, and teamwork during this activity.

Figure 2: A commercially available drone drop clip (Photo by Scott Bellows, Virginia Space Grant Consortium. Used with permission.)

Challenge

While the drop-zone challenge can be tailored for a specific task or environmental setting, here are suggested general instructions:

1. Set up the “drop zone.”
    a. This drop zone should be in a larger area (at least 100 square feet if possible).
    b. The drop zone can be as simple as a target on the floor, or something more creative such as a printout of the surface of the moon or Mars.
    c. You can use tables, tape, or string to establish or delineate the boundaries and targets.
2. Attach a payload to the drone using the drone clip.
3. Position the drone pilot at least 3 feet beyond the boundary of the “drop zone.”
4. Establish safety and flight parameters as needed. For example:
    a. Establish a maximum flight altitude for the operation of the drone (and this altitude can depend on the skill level of the pilot, and the type of drone being used), but it is typically good practice to avoid operating at ‘eye’ level (3 feet of altitude is a great place to start, and you can work to higher altitudes from there).
    b. No one on the team should enter the boundary of the drop zone.
    c. The drone operator and person operating the clip release should be stationary (placing a table at the operator’s position will help them stay in place).
5. Advanced: Other members of the team can walk the perimeter and provide the pilot with feedback on the position of the drone and the release of the payload. When the drone and payload are above the target, the pilot should release the payload.
6. After the payload has been released, the pilot should return the drone to the established landing zone (likely the takeoff zone).

As an addition to this exercise, students can design and build a robotic rover that can be controlled once landed. This activity can be expanded to outdoors once the RPIC is able to take over control of the drone. There should only be one drone operating at a time. This is also a great activity to incorporate a First Person View (FPV) flight.

Notes:

Activity 2: Drone Build

When students build a drone from its basic components, it gives them a better understanding of how the drone operates. Each part contributes to the overall performance of a successful drone flight. Understanding the role of each component will enrich students' knowledge. They can then build custom drones and replace or upgrade components with improved parts to enhance the build. This activity utilizes the REMOKING R605 RC drone build kit, which is an example of a fairly low cost option. There are other drone build options available that also work.

Goal and Objectives

Goal

Students will learn the different parts that comprise a typical quadcopter drone and how to safely operate it.

Objectives

Students will be able to:

1. Identify the individual components of a typical quadcopter drone and what the functional role each part plays in supporting the overall flight system.
2. Assemble a working drone from a kit of parts.
3. Practice flying a quadcopter drone.

Materials

- REMOKING R605 RC drone building kit (fig. 3). This kit can be purchased online at from Amazon (https://www.amazon.com/Remoking-Quadcopter-Headless-360%C2%B0flip-Educational/dp/B07BY473VH). The kit includes:
    - Quad frame.
    - Motors (2 clockwise; 2 counterclockwise).
    - Electronic speed control (built into the flight control board on the mini drones).
    - Radio transmitter and receiver.
    - Propellers (2 clockwise; 2 counterclockwise).
    - Propeller guards.
    - Battery and charger.
- Optional: FPV camera.
- Optional: Obstacle course. Can be purchased on Amazon (https://www.amazon.com/Obstacle-Course-League-Suitable-Exclusive/dp/B076GVLLBD) or you can build your own.

Figure 3: Drone build kit.

Notes:

Instructional Procedures

Identify Drone Components

Using the worksheet provided at the end of this activity, have students identify and label the parts of a drone. The key is provided below for your information.

Figure 4: Frame.

Component Name: Frame (fig. 4)

Purpose: The frame is the skeleton of the build. It determines the number of propellers and the overall shape of the drone. It should be capable of holding all the other components and be strong enough to support the payload.

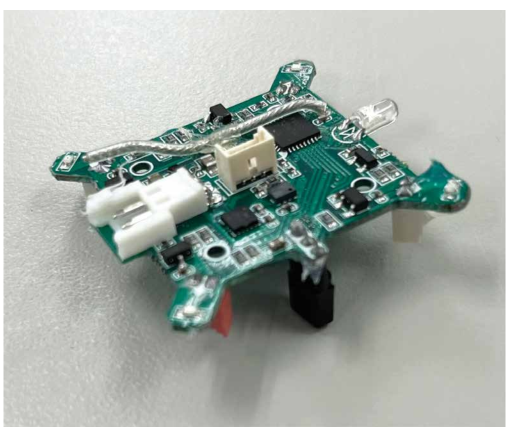


Figure 5: Flight control board.

Component Name: Flight control board (fig. 5)

Purpose: The circuit board comes with a range of sensors that detect movement and can receive information from a transmitter. Common sensors found in a flight control board for quadcopter drones are gyroscopes and accelerometers. This board also includes ESC (electronic speed controllers), which can be a separate component from the board for larger builds.

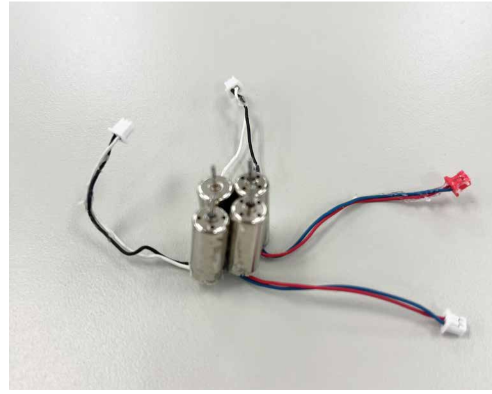


Figure 6: Motors.

Component Name: Motors (fig. 6)

Purpose: The motors on a drone spin the propeller blades to create lift. They can be brushed or brushless motors, depending on the design. There should be two that spin in a clockwise direction and two that spin in a counterclockwise direction. The polarity is secured by the pin attached to the end of these brushed motors but can be reversed in larger builds on brushless motors.

Figure 7: Propeller guards.

Component Name: Propeller guards (fig. 7)

Purpose: Protect propellers from damage in a collision.

Figure 8: Propellers.

Component Name: Propellers (fig. 8)

Purpose: The purpose of propellers on a quadcopter drone is to generate thrust and torque to keep the drone flying and to maneuver. Pay attention to the camber of the blade – there should be two propellers that create lift with a clockwise motor, and two that create lift with a counterclockwise motor. They should be correctly balanced to ensure flight. When builds flip over immediately or will not take off, the problem usually is an incorrect propeller placement.

Figure 9: LiPo battery.

Component Name: LiPo (lithium polymer) battery (fig. 9)

Purpose: The purpose of the battery is to provide power to the control board and motors. LiPo batteries come in various voltages and milliamp hours (mAh, a measurement of the energy capacity of the battery). LiPo batteries should be properly disposed of if they become damaged. Never use a damaged or swollen battery. No battery should be left unattended while charging.

Figure 10: Radio transmitter.

Component Name: Radio transmitter (fig. 10)

Purpose: The purpose of the transmitter is to control the operation of the drone. Some builds will have their own separate receiver attached to the drone, but in this kit, it is embedded in the flight control board. It is important to note that the transmitter and receiver transmit on a standard 2.4 gigahertz signal, which can be intercepted.

Notes:

Assemble the Drone

All custom build kits/projects come with their own level of risk. General safety tips are provided here, but you should research each component of the kit that you will be using with students. If you are building a project from scratch, please be sure to research each part of the project and familiarize yourself with instructions specific to your build.

1. Thoroughly read the instruction manual that comes with your drone kit. This should include safety rules as well as specific preprogrammed flight controls that are associated with your flight control board. Pay special attention to information regarding batteries and charging. Some kits come with multiple flight modes that can be fun for students to experiment with.

2. Start by installing the flight control board to the main body of the drone. It should be secured by snapping a cover or screwing it to the body.

3. Next, install the motors to the body. Be careful to control all wires and secure them so that they are not damaged by the propellers in flight. Be sure to place the motors in the correct location. See figure 11 for standard quadcopter placement.

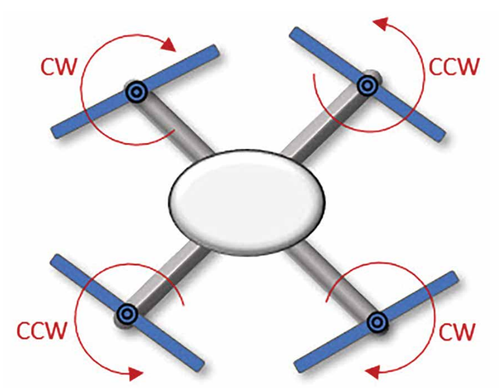


Figure 11: Typical quadcopter motor configuration.

4. Connect the motors to the flight control board (or to the ESCs which are then connected to the flight control board).

5. Attach the propellers and propeller guards to the end of the motors. On a larger build, you should wait to attach the propellers until just before attaching a battery. Some designs require the propeller guards to be installed before attaching the propellers. Be sure to check your manufacturer's guidelines.

6. The last step is to install and connect the battery power supply. Make sure that the battery is securely attached to the frame. Note: Do not overcharge a battery or completely drain it. Never leave the battery unattended while charging, and store at room temperature in a secure location. Follow all manufacturer's specifications for storage and care of LiPo batteries.

7. Generally, you should always turn on the radio transmitter before powering on the drone. However, some kits (like our example) require you to power up the device before turning on the transmitter for it to bind correctly. Read the specific manufacturer's guidelines for binding your transmitter and receiver. Some more advanced control boards also require you to program them for flight and to calibrate sensors. Once you have matched the frequency, you are ready to start flying. The basic "American Hand" mode joystick configuration is provided in figure 12.

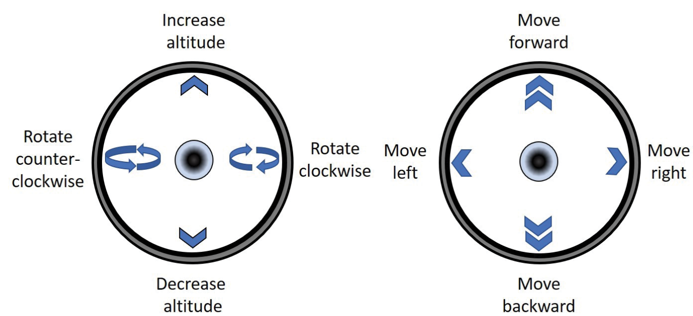


Figure 12: Typical responses of multirotor joystick controls.

8. Practice your flying techniques by maneuvering your drone through an obstacle course with specific tasks to be accomplished. Focus on varying altitude and direction.

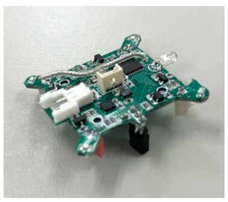
Worksheet: Parts of a Quadcopter Drone

NAME: ______________________________ DATE: ____________________

Directions: Label each of the drone components with its name and purpose.

Component Name:

Purpose:



Component Name:

Purpose:

Component Name:

Purpose:

Component Name:

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Component Name:

Purpose:

Notes:

Activity 3: Tree Measurement

Tree measurement is fundamental to forestry. Tree measurement and growth can tell us a lot about the health of an individual tree or a whole forest. Three basic measurements are commonly used to measure a tree: circumference, height, and average tree crown spread diameter. This activity uses drone technology to measure tree height and the average tree crown spread in a more precise way than traditional methods.

Goal and Objectives

Goal

Students will measure trees and explain how tree measurements are used to assess health of trees and forests. Students will compare traditional methods of measuring and calculating the height and the average tree crown spread to an alternative method, which uses drone technology.

Objectives

Students will:

1. Explain why tree measurement is important.
2. Apply traditional tree measurement processes to measure a tree.
3. Use a drone to capture height and imagery for the crown spread of a tree.
4. Use the calculator on the [Virginia BIG Trees website](http://bigtree.cnre.vt.edu) (http://bigtree.cnre.vt.edu) to determine the score for the tree they measured.
5. Evaluate the benefits of using drone imagery for collecting tree information.

Materials

- A tree.
- Student log (e.g., notebook, laptop, or other item to record data).
- Drone with FPV camera (ensure camera gimbal can point straight down).
- FPV camera app (DJI GO, DJI GO 4, SYMA FPV, etc.).
- Digimizer software (https://www.digimizer.com/download.php) (or comparable software photo measuring tool).
- Tape measure (and the longer the better, but at least twenty feet long or range finder.
- 1-foot ruler.
- Student-made clinometer (use the following components):
    - Protractor.
    - String.
    - Weight (e.g., nut).
    - Drinking straw.
    - Tape.
- Calculator with trigonometry functions.

Instructional Procedures

Identify Tree Species by Name

To compare your tree with others, you must know what species you are measuring. The most common starting point for identifying a tree is by its leaves. Instructors can direct students to do some research to identify the tree, or, to save time, simply provide them with the tree species. Applications such as LeafSnap (fig. 13) make it easy to identify tree species – including the Latin name, which provides more accurate results on the Virginia Big Tree website.

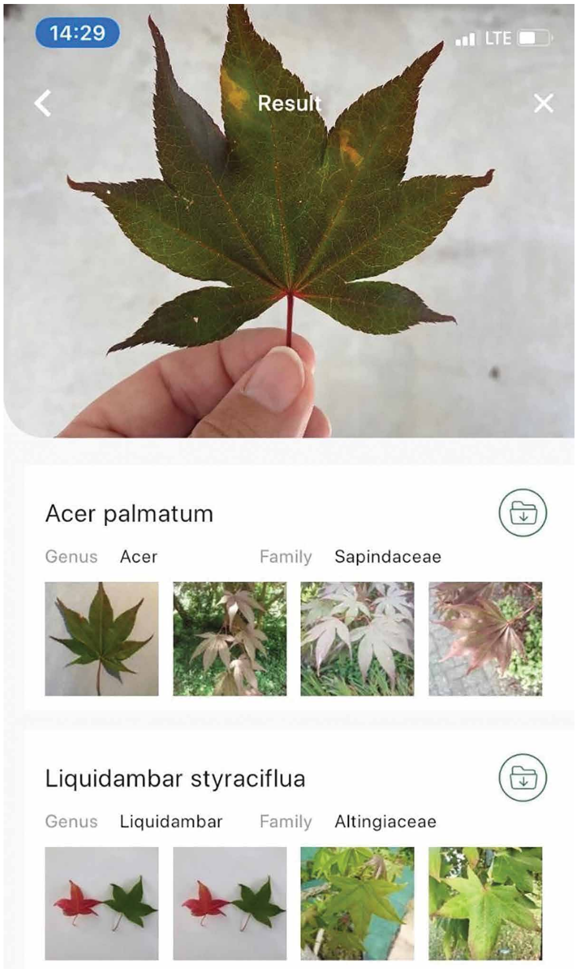


Figure 13: LeafSnap identification of *Acer palmatum*.

Other tree identification resources that can be used include:

- Virginia Tech Tree Online ID Guide (https://dendro.cnre.vt.edu/forsite/key/intro.htm).

- Common Native Trees of Virginia (PDF) (https://dof.virginia.gov/wp-content/uploads/Common-Native-Trees-ID_pub.pdf).

Measure Tree Circumference (inches)

- Wrap a measuring tape around the trunk at 4.5 feet above the mid-slope of the tree's base and record the measurement in inches in your logbook.

- Note: Not all trees have a standard single, upright trunk. Refer to the Diagram of Trunk Forms (fig. 14) to determine the best location for taking your measurement. If you have any trunk form other than No. 1 or No. 6, refer to the American Forests Tree-Measuring Guidelines document that can be found on the Virginia Big Trees website (http://bigtree.cnre.vt.edu/measure.cfm).

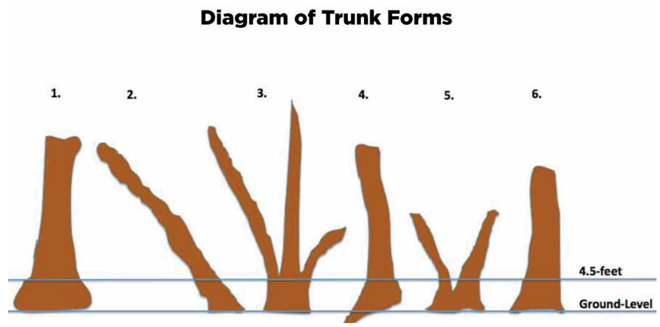


Figure 14: American Forests diagram of trunk forms. (Reprinted by permission from American Forests.)

Measure Tree Height (feet)

Two traditional ways to calculate a tree's height use common math skills. Using both methods provides students the opportunity to compare them, but choosing just one will save time. Another option is to hover a drone at the top of the tree and look at the altitude on the FPV screen to estimate the height.

- **Measure Tree Height (feet) Using Similar Triangles (1-Foot Ruler)**

  Using the geometric principles of similar triangles, if we can find the spot far enough away from the tree that it disappears behind a one-foot ruler (or any object of a known length), then we can calculate the height of the tree. The ratio of **a:A** and **b:B** will allow us to solve for **B** since we can calculate all the other unknown distances with a tape measure. American Forests provides guidelines for measuring the height of trees in this way (fig. 15).

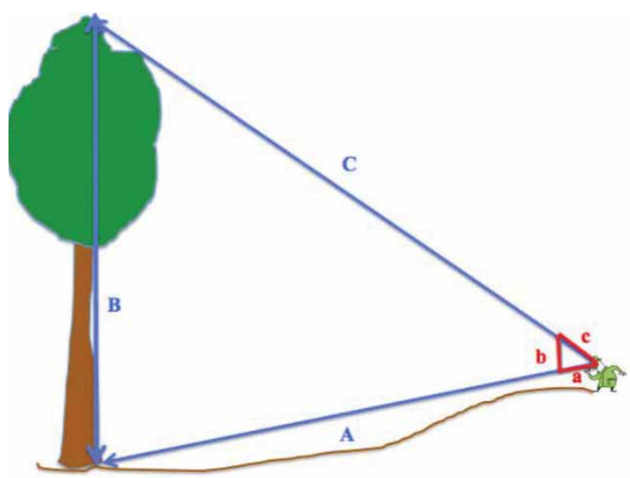


Figure 15: American Forests tree-measuring guidelines. (Reprinted by permission from American Forests.)

1. Hold a ruler vertically at arm's length, and then move forward or backward from the tree until the part of the stick from the top of your hand to the top of the ruler just covers the tree. Keep in mind that a ruler often has spaces at the end of the measurements that are not included in the 12-inch span. Hold the ruler at 0 and align this with the base of the tree, and make sure that the top of the tree disappears at 12 inches, so that **measurement b** is 1 foot. *TIP:* If you are measuring a very tall tree, you may want to substitute a longer stick or yardstick for the 1-foot ruler.

2. From this position, measure the distance from your eye to the top of your hand. This is **distance a**. You can get this distance by extending a string from your eye to your hand and measuring the string length.

3. Next, with a tape measure, calculate the distance in feet from your eye, past the top of your hand, all the way to the base of the tree. This **distance is A**.

4. Solve for **B** (fig. 16), which is the tree's height, and record it in your log (height is recorded in feet).

$$B = \frac{A}{a} b$$

Figure 16: Solve for B using the standard geometrical formula.

- **Measure Tree Height (feet) Using Trigonometry (Clinometer)**

Another method to calculate the height of a tree uses basic trigonometry and a student-made clinometer. For this measurement, you will need to be able to stand at approximately same elevation as the base of the tree.

1. To build a clinometer, tape a drinking straw to a protractor along the base. Then, loop a string through the hole at the origin (the center of the straight edge) and tie a loop large enough to allow the string to freely move along the entire 180 degrees of the protractor. Be sure to leave a good 12-15 inches of string on the other end, and tie a nut or other weight on that end to act as a plumb bob (figs. 17 and 18).

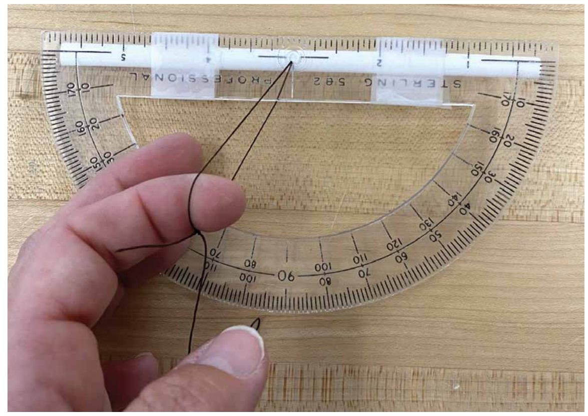


Figure 17: Protractor with straw and string tied to origin.

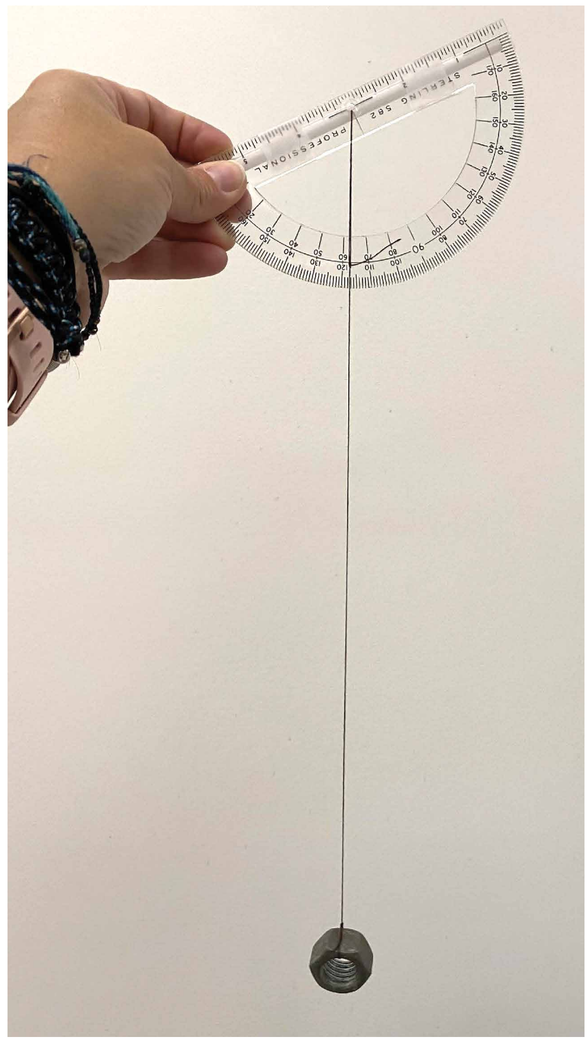


Figure 18: Protractor with weight acting as plumb bob.

2. You will need to be far enough away from the tree so that you can see the top of the tree through the straw of your clinometer. As you peer up to the top of the tree, the place where string crosses the rounded part of the protractor will indicate the angle, A1 (fig. 19).

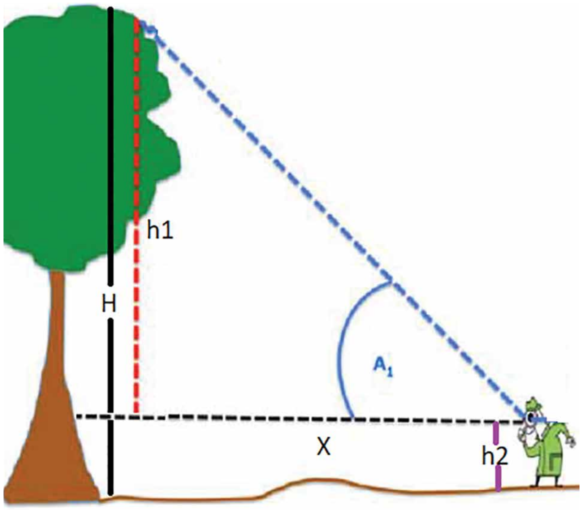


Figure 19: Measuring the height of a tree using a clinometer. (Reprinted by permission of American Forests.)

3. Measure your distance away from the tree trunk in feet. This **distance is X**. An approximate measurement will work for this method.

4. Use basic trigonometry to calculate your unknown value **h1**. Since we know the adjacent side (X) and we need to know the opposite side (h1), the best operation to use is tangent. *TIP:* Be sure your calculator is in degrees mode and not radians, and keep your units consistent between feet and inches.

$$X * TAN(A1) = h1$$

5. Calculate the height of h2 by measuring from your feet to your eyes. Add that value (in feet) and add that to your calculated h1 value to get the overall height (H) of the tree.

6. Record this measurement in your student log.

- **Measure Tree Height using a Drone**

1. Fly the drone until it is at the same height as the tallest point of the tree.

2. Look at the altitude of your FPV application to see what altitude the drone is recording (altitude is measured from the elevation of the home/takeoff point). It is helpful to have other visual observers assist in estimating when you have reached the right height by looking at it from different perspectives (fig. 20)

Figure 20: FPV application view showing altitude measurement.

Measure Average Tree Crown Spread Diameter (feet)

Crown spread is the horizontal separation of two points on opposite sides of the crown (fig. 21). You can either select an average crown width (by eyeballing it) or the maximum crown width. For a more scientific approach, you can measure the widest distance of the crown, and measure the shortest distance of the crown, and use the average of these two measurements. The horizontal line joining the two points may or may not run through the trunk.

Crown size is typically calculated by measurements taken from the ground. However, there are often limitations associated with traditional ground measuring techniques to measure crown spread. These limitations can include:

- Crown edges are inaccessible (over water, difficult terrain, or hidden from view by understory tree canopy).
- Complex trunk forms.
- Tree spans uneven ground (measuring slope instead of horizontal distance).

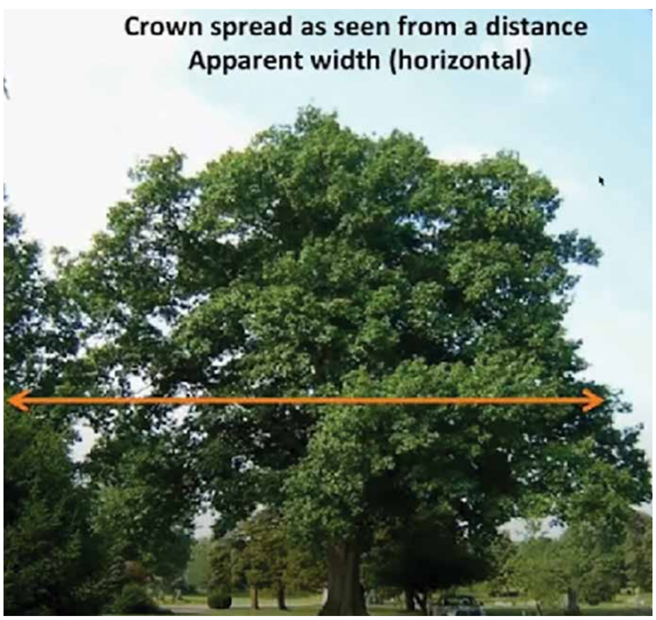


Figure 21: Tree crown spread with apparent width indicated.

When you take tree crown edge measurements from the ground, you must project the tree crown onto a horizontal plane (as if the crown of the tree was over perfectly flat terrain). The outline of this tree crown surface is called the drip line. Using a drone allows us to delineate the edge of the crown (the drip line) onto a horizontal plane above the tree.

Drip line measurements captured from a drone are more efficient and accurate. Use the steps below to measure tree crown spread using a drone.

1. Take a picture of the tree crown using the drone. The image should be taken from a camera that is pointing directly down at a 90 degree angle (fig. 22). Be sure to include an object of known size in the image for scale reference to get an accurate measurement.

Figure 22: Drone image of tree crown, with camera pointing straight down.

2. Open the image in an image measurement tool. These instructions are based on Digimizer, free Windows PC software.

3. The first step is to establish the units using a known measurement of something in the image. In figure 23, the sidewalk, which is 3 feet wide, acts as the known measurement.

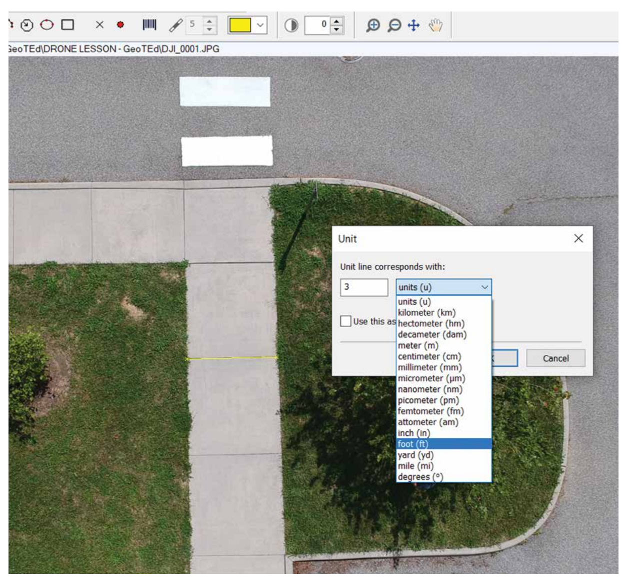


Figure 23: Establishing reference units to measure tree crown in Digimizer.

4. Now you are set up and ready to start taking measurements! There are two ways to calculate the average tree crown spread diameter: the two-diameter/axis method or the spoke method. Both are outlined below, but the spoke method has more data values, which make it more accurate. Comparing the two methods provides a good opportunity to discuss measurements and statistics.

5. **Two diameter/axis method:** Measure the greatest spread around the drip line of the tree, and then measure 90 degrees to that line, and get an average of the two measurements (fig. 24). In this method, the lines are labeled A and B. Those lengths are added together and divided by two to get the tree crown spread measurement.

$$\frac{A+B}{2}$$

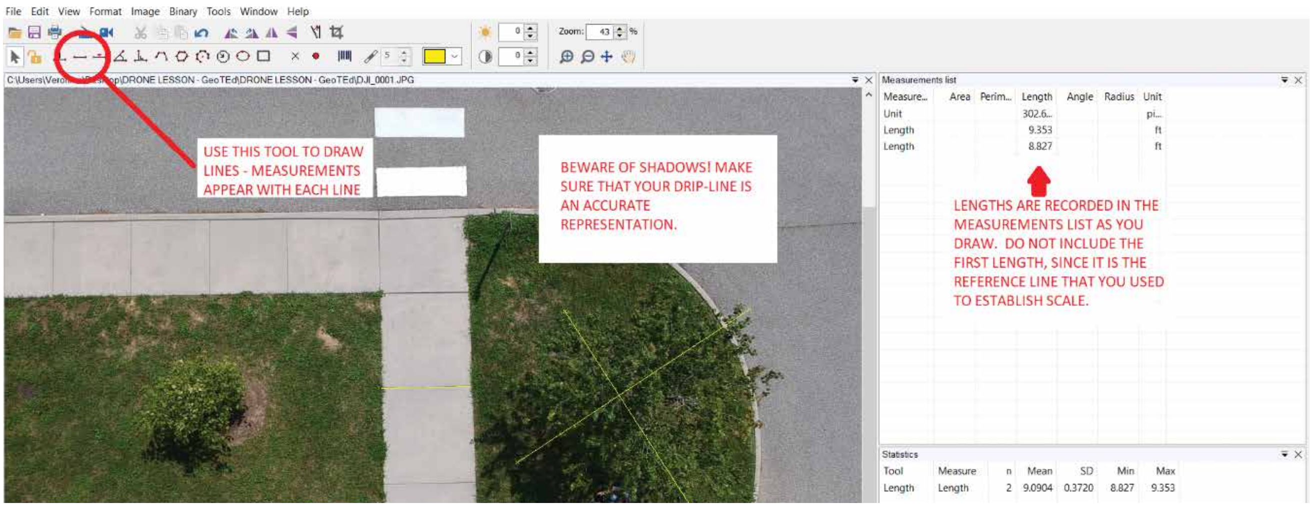


Figure 24: Two diameter/axis method in Digimizer.

6. Spoke method: Take multiple measurements through the center of the crown spread (in a spoke pattern) and average them (fig. 25). In this method, eight lines are labeled A through H. The lengths are added together and divided by eight to get the crown spread measurement.

$$\frac{A+B+C+D+E+F+G+H}{8}$$

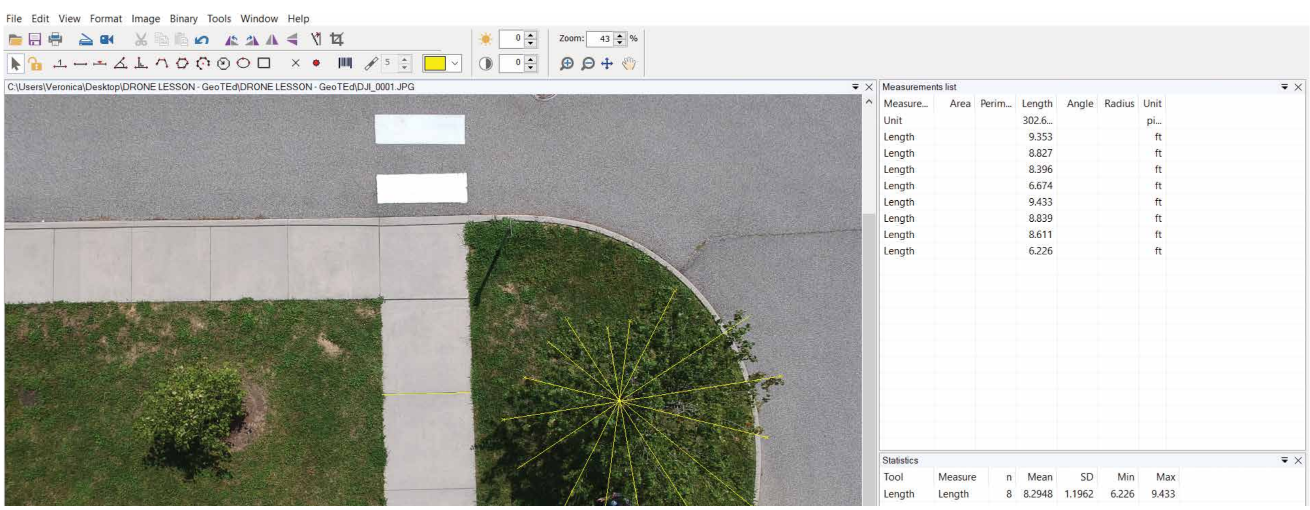


Figure 25: The spoke method in Digimizer.

You now have all the tree measurements that you need to see how this tree compares to other trees of the same species. Go to the [Virginia Big Tree website](http://bigtree.cnre.vt.edu/measure.cfm) (http://bigtree.cnre.vt.edu/measure.cfm), enter your information, and see how scores are calculated.

Supplemental Information

Leverett, B., and Bertolette, D. n.d. “Measuring Guidelines Handbook: National Register of Champion Trees.” American Forests. Accessed August 29, 2020. https://www.americanforests.org/wp-content/uploads/2019/07/AF-Tree-Measuring-Guidelines_MW.pdf.

Notes:

Notes:

Activity 4: Phenology

Many natural events are seasonal, such as frogs calling, trees leafing out, and birds migrating. Several factors such as day length and temperature can influence the occurrences of these events. However, climate change is altering the traditional timing of many natural events. This lesson will allow us to create a long-term project to document tree phenology changes due to climate change.

Goal and Objectives

Goal

Students will photograph trees from a drone on the same date each spring and fall. Students will measure the amount of canopy that is green and compare their values to previous years to determine if trees leaf out and fall foliage dates occur earlier or later.

Objectives

Students will:

1. Define "phenology."
2. List three natural events that now occur earlier due to climate change.
3. List two factors that can influence the dates that trees produce and lose leaves.
4. List two ways changes in natural phenology impact humans.

Materials

- Student log (e.g., notebook, laptop, data sheet, or other item to record data).
- Drone with FPV camera (ensure camera gimbal can point straight down).
- Tree identification guide, like "Common Native Trees of Virginia" (downloadable at https://www.dof.virginia.gov/infopubs/Native-Tree-ID_2020.pdf).
- A study area with several distinct trees of various ages, sizes, and species. (Please ensure you have permission to fly from the property manager and the FAA).

Background

Phenology is the branch of science dealing with the relationship between climate and periodic biological phenomena (such as bird migration or plant flowering).

- List three other periodic biological phenomena.

The emergence of leaves on trees is often viewed as a sign that spring has arrived, and the same leaves changing colors also ushers in fall. However, temperature is not the only factor that influences when trees produce and lose their leaves. (See the U.S. Forest Service's Science of Fall Colors web page (https://www.fs.usda.gov/visit/fall-colors/science-of-fall-colors)

- List two other factors that might influence the production and loss of leaves on trees.

Global temperatures have increased by 1 degree Celsius from preindustrial times to 2017. In many areas, temperatures have increased by more than 1.5 degrees Celsius (IPCC 2018). Climate change has and will greatly impact the timing of many natural events. Seasonal events will occur earlier. Budding leaves on trees and blooms on flowers are a sign spring has arrived and could signal earlier springs. "Tracking spring" is a fun activity to watch spring arrive in the southernmost portions of the United States and follow its progression northward. The USA National Phenology Network maintains a great website (https://www.usanpn.org/news/spring) to allow students to observe spring progression from the South to the North and how the current year compares to past years.

- Is this year's spring earlier or later than last year? How does this year compare to the 30-year average?

Changes in natural timing do not just impact wildlife and plants; humans are impacted as well. The timing of flowering plants can impact allergy suffers. Climate change is impacting the length of time that plants have flowers. For example, the pollen season for ragweed is now between 13 and 27 days longer than it was in 1995 (Ziska, Knowlton, and Rogers 2016). Changes in rain cycles can impact disease-carrying mosquitoes. Growing seasons and drought frequencies are increasing due to climate change, impacting the food we consume (USDA, n.d.).

- What is another potential impact that a change to natural timing would have on humans?

Sometimes changes in phenology might not have a direct impact on a species. The great tit (*Parus major*) is a small songbird found in Europe. When the great tit's eggs hatch, the parents feed their young birds caterpillars. The main food source for the young caterpillars are buds and young leaves of English oak (*Quercus robur*). From 1985 to 2004, caterpillar abundance was peaking three days earlier every four years (Visser and Holleman 2006) due to increasing temperatures and oaks budding earlier. The birds are also laying their eggs earlier due to warming temperatures. However, the birds are not increasing their first egg-laying date quickly enough to keep up with the caterpillars. Thus, when the new birds hatch, there is often not enough food to feed them since the hatch is out of sync with caterpillar populations. Therefore, due to climate change, the events that once were timed perfectly are now mismatched (Visser and Holleman 2006).

- With birds now hatching later than caterpillars emerge, what effects could that have on the birds, caterpillars, and oak trees?

Documenting phenology changes is the first step in understanding complex relationships such as the great tit, caterpillars, and English oak trees. In this exercise, you will create, and in future years be adding, to a long-term data set to gain a greater understanding of how climate change will impact the phenology of trees.

Instructional Procedures

Learning Activity: Observe and document changes in leaf emergence and fall foliage dates over time.

Methods

- Students will fly drones above trees on the school grounds on the same date each year (e.g., first Monday in May and second Monday in October) as long as favorable weather conditions exist.
- Students will use the public domain image processing program ImageJ to determine the amount of green (in spring) or lack of green (in fall) in the tree canopy.
- Students will summarize their findings so that students in future years will be able to compare data.

1. The teacher will identify at least five different trees on school grounds or a nearby property available for flights. It is best to use trees of different ages, sizes, species, and distances away from buildings.
2. Have students identify the species of the trees being used in the activity. The Virginia Department of Forestry has excellent resources (https://dof.virginia.gov/education-and-recreation/learn-about-education-recreation/tree-identification/) and great publication, Common Native Trees of Virginia (https://dof.virginia.gov/wp-content/uploads/Common-Native-Trees-ID_pub.pdf), that is available online for identifying native trees to species and Environmental Conservation also has a website (https://dendro.cnre.vt.edu/dendrology/idit.htm) to help identify trees. These resources can be used in other states as well.
3. Follow all safety and FAA procedures for drone flights.
4. Fly above the tree, ensuring that the entire canopy is in the frame while minimizing any shadows.
5. Each student or group of students can be assigned an image to analyze.
6. Follow the ImageJ procedures to compare the amount of green versus nongreen in the canopy.
7. Have students compare their percentages to the same dates from previous years. During the

first year, teachers can discuss how the trees might have looked last year and have students speculate on how dates might change in the future, since previous years' data would not be available.

Example Tree Photographs

This sycamore tree was flown as it was changing to fall foliage (fig. 26). Note the shadows on the left side of the tree. Try to eliminate shadows in your photograph by operating your drone at midday, or during a cloudy day. Eliminating shadows can make the delineation of the crown easier.

Figure 26: Drone image of a sycamore tree in the early fall.

This silver maple was photographed in winter. Note that it is possible to observe the individual branches of the tree. Different species often support different branch patters. (fig. 27).

Figure 27: Drone image of a silver maple in winter. (Photo by Jason R. Davis, J. Davis Photography. Used with permission.)

Measuring Tree Canopy Greenness Using ImageJ

Note: ImageJ is one of several free image processing software options that can be used. For a list of other options, visit the Virginia View website (https://virginiaview.cnre.vt.edu/software-apps/), and scroll down to "Remote Sensing Software (free)."

1. Download the open access program on the ImageJ website (https://imagej.nih.gov/ij/) from the National Institutes of Health.

2. Once installed, open the program. It has a small interface window (fig. 28).

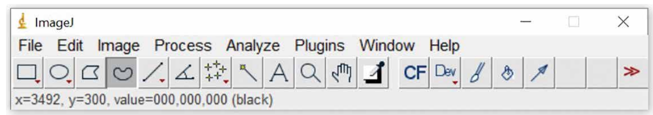


Figure 28: ImageJ menu.

3. Next, select **File -> Open** and choose your picture to upload.

Your tree should look similar to our sample (fig. 29), although images without a shadow will be easier to work with.

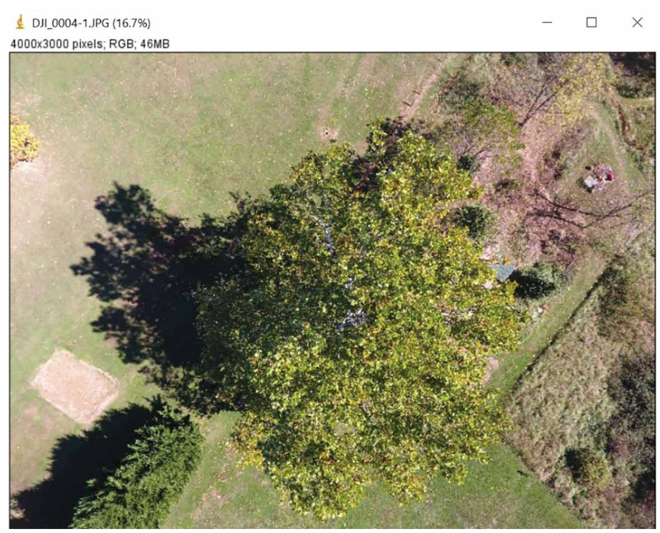


Figure 29: Sycamore tree crown image in ImageJ.

4. Use the freehand drawing tool to carefully outline the perimeter of the tree canopy. The tool works by clicking the mouse and moving around the perimeter.

5. You will see a yellow line around the perimeter (fig. 30).

Figure 30: Perimeter of sycamore tree crown in ImageJ.

6. Now select **EDIT -> CLEAR OUTSIDE**. This will remove the area on the outside of the tree (fig. 31).

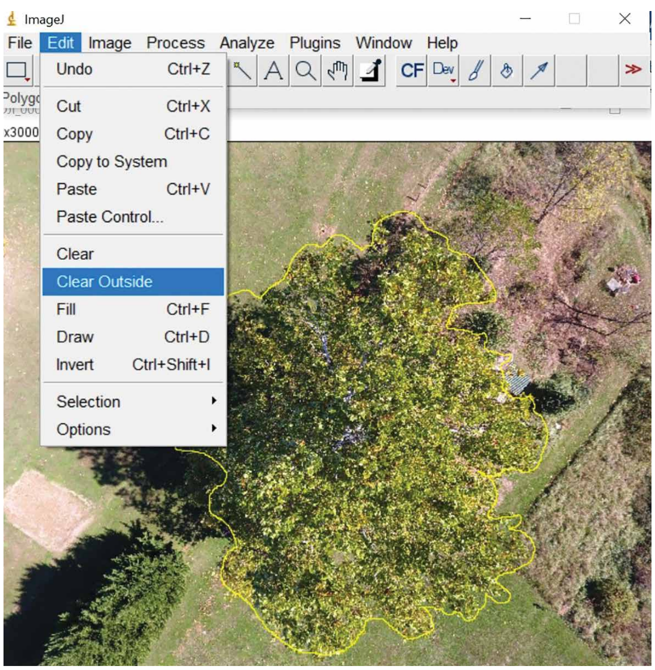


Figure 31: Removing the area outside the tree perimeter in ImageJ.

7. Your image should now resemble the image below (fig. 32).

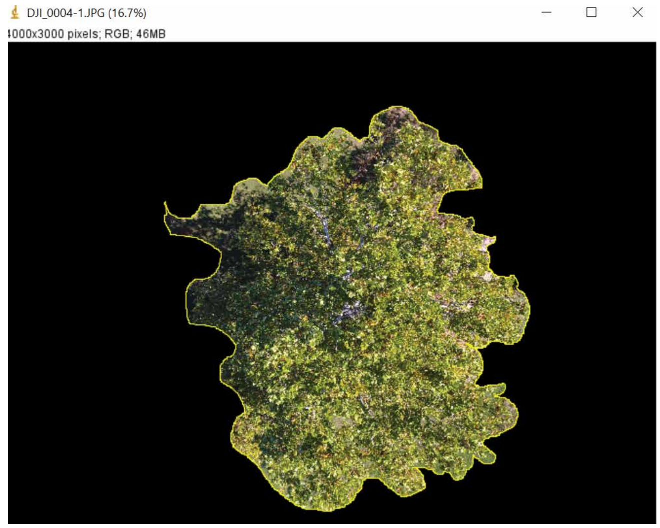


Figure 32: Tree perimeter in ImageJ.

8. Let's measure to determine the number of pixels the comprised by the canopy (fig. 33). Select **ANALYZE -> MEASURE**.

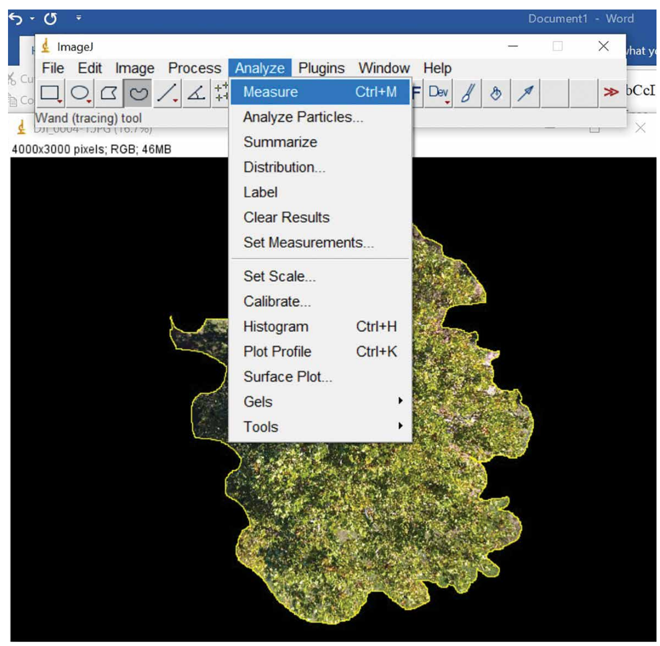


Figure 33: Measuring the number of pixels in the canopy using ImageJ.

You will be provided a window with the measurement values (fig. 34).

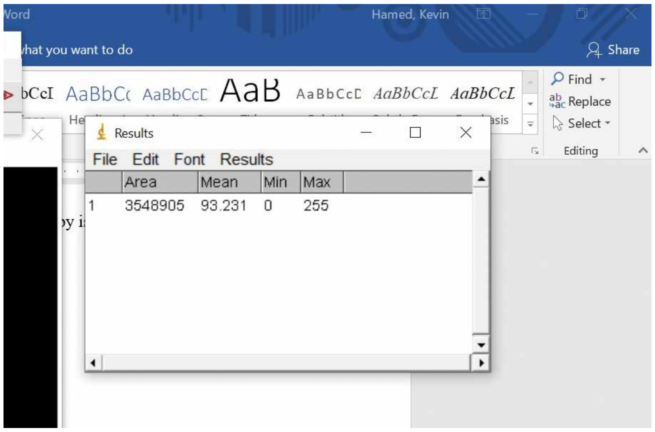


Figure 34: Resulting pixel count in ImageJ.

9. Record the pixel value: 3,548,905 (The value from your image will be different.) You can minimize the results window.

10. Now we will determine how much of the tree canopy is green (fig. 35). Select **IMAGE -> ADJUST -> COLOR THRESHOLD**.

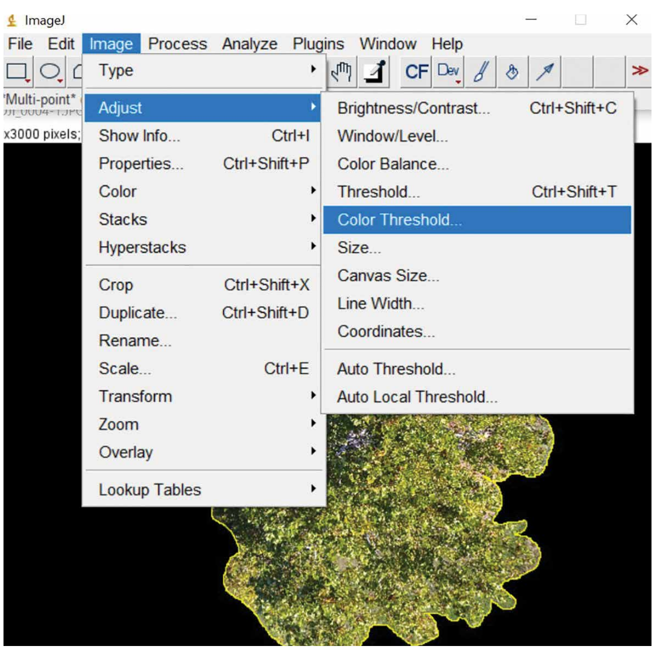


Figure 35: Determining how much of the canopy is green in ImageJ.

11. When the Threshold Color Window appears, make sure you choose RGB for the color space option (fig. 36).

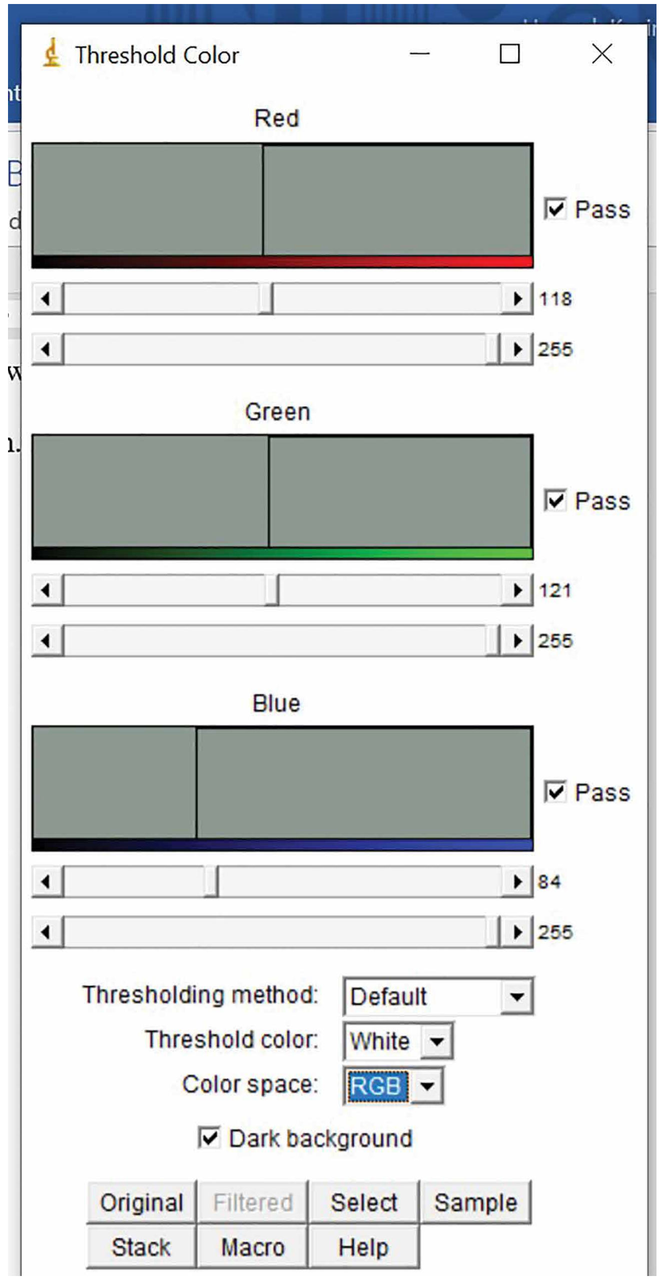


Figure 36: The Threshold Color window in ImageJ.

12. Adjusting for "Threshold Color" in ImageJ separates the picture's foreground from its background. This allows you to drop out all color from the background to get an accurate measurement of the color in just the canopy, not the ground beneath it. In this example, the threshold color is white. However, you can also choose red. As you adjust the sliders under the green, blue, and red color options, the areas under the canopy turn to the threshold color. You will move the slider to the lower position and note if the background is changing to the color you have chosen, red or white. If the background is not reaching your desired color, move the slider to the higher position. The task has been

successfully completed when the background color reaches your preferred color. You also can toggle back and forth between ORIGINAL and FILTERED to ensure you are removing any areas that are not part of the canopy (fig. 37).

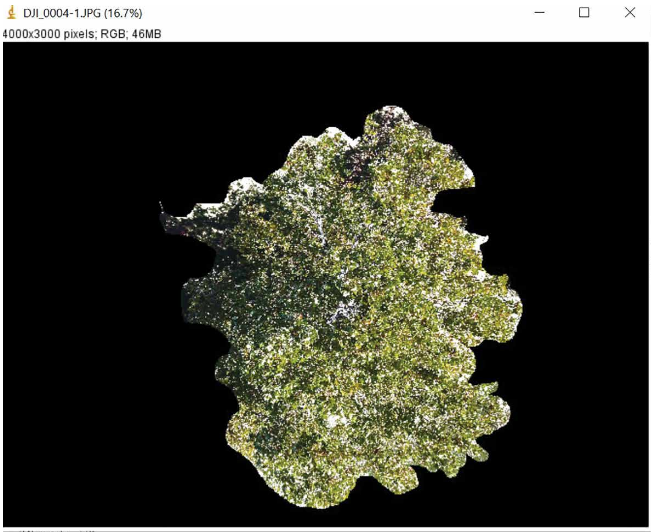


Figure 37: Adjusting the color threshold in an image separates the background from the foreground. In this image, the background, or threshold, is in white.

13. When you are satisfied that you have removed all non-green, non-leafy areas, click SELECT. Your image should resemble the image in figure 38.

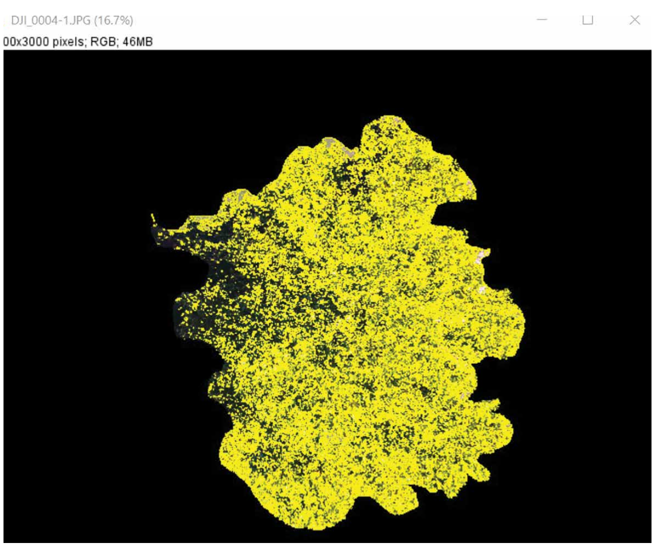
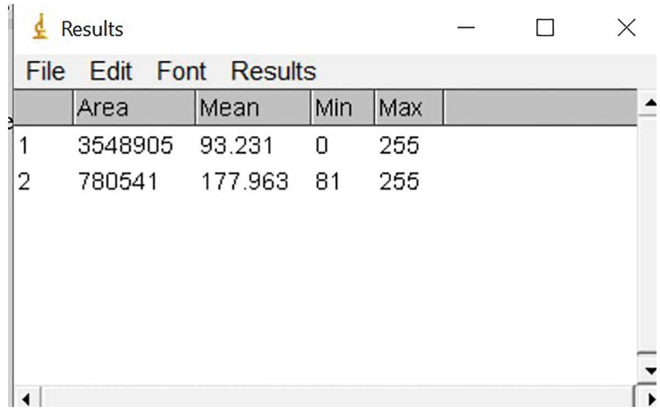


Figure 38: Completed image in ImageJ.

14. Now remeasure your image (Select **ANALYZE -> MEASURE**). The first result is the original area of the canopy you calculated in step 8 (fig. 39). The second result is the number of pixels in the new image that are not green. Subtract the second number from the first, and then divide the result from the first number to find the percentage of the canopy that is green. In this example, (3,548,905 – 780,541)/3,548,905 = 2,768,364/3,548,905 = 0.78. That means in this image, 78% of the canopy is green. Record your findings on a Phenology Data Sheet (tables 1 and 2, at the end of this activity) or in your logbook.



	Area	Mean	Min	Max
1	3548905	93.231	0	255
2	780541	177.963	81	255

Figure 39: Second pixel count (number of non-green pixels in ImageJ).

- Why is it necessary to calculate a percentage of green canopy, as opposed to just determining the number of green pixels, when comparing trends over the years?

15. This can be repeated for on the same day each spring and fall. Students can graph the results to determine if the amount of green tree canopy is greater or less than previous years. More green pixels in the spring and fall would suggest a longer growing period, most likely due to climate change. Both temperature and moisture affect leaf color, and both are influenced by our changing climate. For more information on tree color, see the Science of Fall Colors web page (https://www.fs.usda.gov/visit/fall-colors/science-of-fall-colors) from the U.S. Forest Service.

References and Supplemental Information

IPCC (Intergovernmental Panel on Climate Change). 2018. "Global Warming of 1.5 Degrees C: An IPCC Special Report on the Impacts of Global Warming of 1.5° C Above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty." V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, et al., editors. https://www.ipcc.ch/sr15/.

USDA (U.S. Department of Agriculture). n.d. "Growing Seasons in a Changing Climate." Accessed February18, 2021. https://www.climatehubs.usda.gov/growing-seasons-changing-climate#:~:text=The%20effects%20on%20seasons%20of,increased%20in%20frequency%20and%20severity.

Visser, M.E., and L. J. M. Holleman. 2006. "Shifts in Caterpillar Biomass Phenology Due to Climate Change and Its Impact of the Breeding Biology of an Insectivorous Bird." *Oecologia* 147: 164–72.

Ziska, L., K. Knowlton, and C. Rogers. 2016. "Ragweed pollen season." Accessed February 18, 2021. https://www.arcgis.com/home/item.html?id=c2e518abce9a4ffe98740f574fa02b92. National Allergy Bureau, Aerobiology Research Laboratories, Canada. Update to data originally published in: Ziska, L., K. Knowlton, C. Rogers, D. Dalan, N. Tierney, M. Elder, W. Filley, et al. 2011. "Recent Warming by Latitude Associated with Increased Length of Ragweed Pollen Season in Central North America." *Proceedings of National Academy of Science* 108: 4248–51.

Websites

- USA National Phenology Network (https://www.usanpn.org/about/why-phenology).

- How Climate Change is Shifting Nature's Timing, from the World Economic Forum (https://www.weforum.org/agenda/2015/01/how-climate-change-is-shifting-natures-timing/).

Discussion Questions

- Are there other species that might be impacted by trees on our school grounds leafing out early?

Have students examine native birds that eat caterpillars. The yellow-billed cuckoo (*Coccyzus americanus*) is a great example. These birds often arrive from Central America each spring when eastern tent caterpillar (*Malacosoma americanum*) emerge. Learn more about the yellow-billed cuckoo on the All About Birds website (https://www.allaboutbirds.org/guide/Yellow-billed_Cuckoo/overview).

- Could climate change negatively impact trees and even reduce the amount of green foliage?

Diseases can greatly influence tree health and subsequently the amount of green in leaves. Climate change seems to be increasing the severity and spread of these pathogens. Have students review a few of the common tree pathogens found in Virginia on the DOF website (https://dof.virginia.gov/forest-management-health/forest-health/insects-and-diseases/). Are any of these present on your school grounds?

Drought impacts leaf color especially in the fall. Have your students review the U.S. Drought Monitor website (https://droughtmonitor.unl.edu/) from the University of Nebraska-Lincoln. Students can explore the time series graphs to review past 20 years of droughts. Could droughts impact this project?

Sample Data Sheets

Table 1. Spring Phenology Data Sheet

Tree Species	Percent Green	Average Percent Green from the past five years	Is this year's leaf out date earlier or later?

Table 2. Fall Phenology Data Sheet			
Tree Species	Percent Green	Average Percent Green from the past five years	Is this year's leaf out date earlier or later?

Notes:

Activity 5: Using Drones for Counting Wildlife

Having an accurate population census is necessary for managing wildlife populations. In the past, wildlife counts required biologists to be on the ground and count individual animals. This activity shows how to use drone technology to count individuals within a wildlife population. It can be conducted with a mapping drone (e.g., Mavic, Phantom, Skydio) or a First Person View (FPV) drone, such as a Tello.

Goal and Objectives

Goal

Students will count a sample wildlife population from the ground and by using a drone. Students will compare their counts to determine which method is most accurate for wildlife biologists.

Objectives

Students will:

- List three reasons why wildlife biologists need accurate population counts.
- List four factors that impact the growth rates of wildlife populations.
- Count a sample wildlife population from the ground.
- Use a drone to capture imagery of the sample wildlife population.
- Use aerial imagery to count the sample wildlife population.
- Compare ground and aerial counts and determine the most accurate method.
- Evaluate the benefits of using drone imagery for locating and counting wildlife as the climate changes.

Materials:

- Student log (e.g., notebook, laptop, data sheet, or other item to record data).
- Drone with FPV camera (ensure camera gimbal can point straight down).
- A sample animal population. (Note: Flying over wildlife is not permitted in many areas but you could count a herd of domestic animals with proper permission.)
- An alternative to live animals would be to use decoys:
    - Plastic duck decoys.
    - Student-made ducks or geese (links provided in the lessons).

Background

Managing wildlife populations requires frequent counts of individuals within a population (a group of individuals of the same species within a defined area).

- What are three reasons wildlife biologists need to know the current number of individuals in a population?

To help manage wildlife populations, wildlife biologists must know the size of the population and if the population's growth rate is increasing or decreasing. Animals that are classified as rare or endangered require frequent population counts. Accurate population numbers provide managers with data to determine if laws and habitat improvement projects are benefiting the wildlife.

Especially important to wildlife managers is understanding the population growth rate.

- List four factors that would determine if a population was increasing, decreasing, or remaining the same. What would add to a population? What would remove individuals from a population?

Population growth rate is expressed with the following formula:

Population Growth Rate = (b+i) – (d+e)

b = birth rates (number of animals born in the population)

i = immigration rates (number of animals that move into a population)

d = death rates (number of animals that perish in the population)

e = emigration rates (number of animals that leave to join another population)

Immigration and emigration are not the same as migration. Many animals that migrate come back to their same breeding and wintering grounds each year (e.g., many songbirds spend winters in Central America). Animals that immigrate and emigrate permanently leave their original population.

Censusing (counting) individuals is a requirement for wildlife biologists.

- How did wildlife biologists count individuals before drones?

Historically and even today, many wildlife populations are counted by wildlife biologists observing and counting individuals in the field. Counting individuals in the field could entail hiding in a blind and counting individuals (e.g., counting deer in a forested area), placing stationary cameras to count individuals (e.g., jaguars in a dense rainforest canopy), or counting individuals using crewed aircraft (e.g., counting ducks in lakes or ponds). Using crewed aircraft to count wildlife is a dangerous endeavor (Sasse 2003). These aircraft must operate at low altitudes, which is extremely risky for the pilots and wildlife biologists in the aircraft. These aircraft are also noisy, which could potentially scare wildlife, causing them to scatter and hide.

The public can also contribute to these important counts by participating in events such as the Audubon Society's Great Backyard Bird Count or FrogWatch USA. Achieving an accurate count can be challenging, as observing all individuals is not always possible.

- What are three reasons why it might be difficult to count all individuals within a population?

Examine the picture of shorebirds (red knots or *Calidris canutus rufa*), in figure 40 on the Eastern Shore of Virginia. How many birds can you see? Did you miss any? If so, why?

Figure 40: A flock of red knots on the Eastern Shore of Virginia. (Photo by Sarah Karpanty, Virginia Tech Department of Fish and Wildlife Conservation. Used with permission.)

Observing wildlife populations, such as shorebirds or deer, from above would provide wildlife biologists a much better view and allow for more accurate counts. Drones can provide biologists with a safe and cost-effective solution to count individuals from above.

- What are the potential benefits and drawbacks of using drones to count wildlife?

Wildlife biologists must consider climate change while managing wildlife populations. The changing climate will present even more challenges to biologists in the future.

- Name three impacts climate change will have on wildlife in the future.

Uncrewed aircraft (drones) can also help wildlife biologists locate individuals after severe weather events such as hurricanes, floods, and fires.

A 2020 Bloomberg News article, "Using Drones to Rescue Wildlife from Climate Disasters," provides excellent examples of drones helping wildlife biologists after severe climate events. It is available on the Bloomberg website (https://www.bloomberg.com/features/2020-drones-wildlife/).

In addition, an NPR article from 2021 (https://www.npr.org/2021/02/17/968719492/), "Volunteers In Texas Are Saving Thousands of Cold-Stunned Sea Turtles from the Storm," shows how community support can make a difference to help endangered wildlife during a crisis.

- How could drones be employed to help save the turtles?

Instructional Procedures

Learning Activity: Compare population counts from drones with those conducted using ground-based surveys.

Methods

- Students will count a population of "wildlife" from the ground and then from images taken from a drone above the same population.

- Since many states prohibit flying over wildlife without permits, especially on public lands, teachers can use domestic animals such as cows if they are available near the school campus. Be sure to gain permission from the farm owner well in advance.

- Alternatively, students could make their own fabricated "wildlife," such as mock ducks or geese, for the project. This portion of the lesson allows for collaboration with art classes.

    - Ducks can be made from empty bleach bottles, white one-gallon milk jugs, or similar containers, in which each student draws or paints a similar pattern on each bottle. Another option is to use small blocks of cork and cardboard to make ducks, as explained in a 2014 Farm and Dairy do-it-yourself article (https://www.farmanddairy.com/columns/diy-homemade-duck-decoys-can-trick/209971.html).

    - Geese can be made from white trash bags that are painted with cardboard heads and feet. Directions can be found in a 2012 Outdoor Life article (https://www.outdoorlife.com/photos/gallery/hunting/turkey-waterfowl/waterfowl-techniques/2012/08/how-make-your-own-decoys/).

    - Duck decoys are available for purchase, and a few vendors are listed in the teaching resources at the end of this activity. However, this option could be cost-prohibitive.

- Use your creativity to design other species of fabricated wildlife for the lesson.

1. If domestic animals are being used, the teacher or leader of this activity will arrange for students to stand in a safe area where they can see the animals. If mock wildlife is being used, place the wildlife models in an open area (e.g., athletic field or playground). If each student has made a figure, be sure to add several extra to prevent students from assuming the flock size is the same as the class number. You can use different sizes to distinguish adult wildlife from juvenile wildlife.

2. Have students stand 30 to 40 meters from the edge of the population being counted.

3. Each student can make an individual count, or the group could count the flock multiple times. Either way, calculate the average of the counts to get the total. Record the count in a logbook, data sheet (table 3, at the end of this activity), or in another way.

4. For drone flights, follow all local and FAA procedures. The project leader should obtain an FAA Part 107 Remote Pilot Certificate.

5. After the students complete the ground-based counts, fly a drone above the animals or models to take several pictures. Pictures can be taken at 30, 60, 90, and 110 meters. However, due to FAA regulations, the pilot must ensure the drones do not fly higher than 400 feet (121 meters) above the ground to comply with FAA regulations.

6. Upon the safe conclusion of the flight, provide students with access to the digital images taken from the drone. Be sure students conduct counts the same number of times from the drone pictures as they did during the ground-based count. Record the count.

7. Have students compare ground and drone counts. Students can calculate the difference between the two methods.

8. Students should compare and contrast the two methods. Would there be situations where either method would be advantageous or prohibitive?

Example 1

This illustration uses cows around a watering trough. Review the images (figs. 41 and 42) taken from the ground next to a watering trough to approximate how many cows are around it. Do not count the cow in the distance, noted with a circle in figure 41. Write down the class approximations for each image.

Figure 41: Looking southeast at the cow grouping, it's challenging to determine an exact number given the distance between the cows and the hill. (Photo by Maddie Hamed. Used with permission.)

Class Approximation: ______________________

Figure 42: Looking directly east, it's easier to see some of the cows but they still blend together. (Photo by Maddie Hamed. Used with permission.)

Class Approximation: ______________________

Now examine pictures taken from above with a drone approximately 200 feet above the ground. First, look at figure 43. Can you count the cows? Write your estimate below the photo.

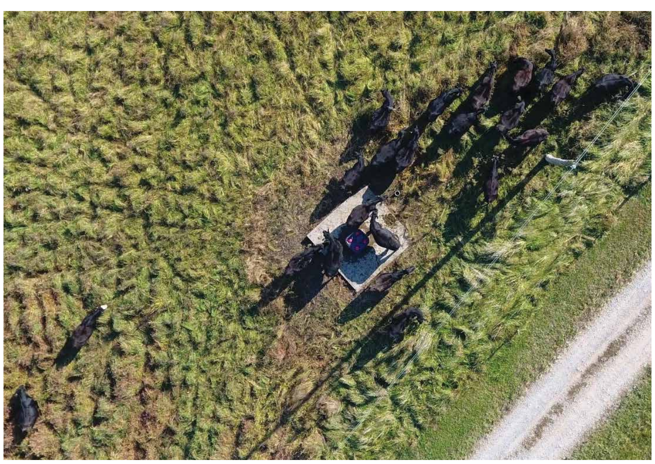


Figure 43: Aerial image of cows gathered at a watering trough taken directly above from a drone. (Photo by Virginia Tech's Department of Forest Resources and Environmental Conservation.)

Class Approximation: ______________________

From the drone: What if we zoom into the group by the water trough (fig. 44)? Write down your count below.

Figure 44: Drone image of cows zoomed in to the group by the water trough. (Photo by Virginia Tech's Department of Forest Resources and Environmental Conservation.)

Class Approximation: ______________________

The zoomed image allows us to identify 18 cows (fig. 45). Two other cows to the left of the water trough were cropped out of this image because of the zooming in. So, with aerial images, we can identify 20 cows near the water trough.

Figure 45: Circles identify individual cows in the drone image. (Photo by Virginia Tech's Department of Forest Resources and Environmental Conservation.)

- How well did the ground counts approximate the total number of cows?

  20 – ground count approximation = number of miscounted individuals

- Did the ground counts over or underestimate the total number of cows?

- How could miscounting impact a wildlife biologist?

Example 2

For this example, place various sized traffic cones inside a fenced-in tennis court (fig. 46). Strategically place them to allow smaller cones to be hidden behind larger ones. Tell students to go around the fence, each counting the cones. Afterward, ask students to discuss their individual cone counts with their group members and decide on one count for their group. Compare their result with the actual number of cones on the court.

Next, fly a drone over the court and take overhead pictures (fig. 47). Ask students to count the cones in the pictures and compare results with the ground-level count.

Figure 46: Fenced-in tennis court with traffic cones for students to count. (Photo by Virginia Tech's Department of Forest Resources and Environmental Conservation.)

Figure 47: Drone image of the tennis court from above. (Photo by Virginia Tech's Department of Forest Resources and Environmental Conservation.)

How did your findings compare to those of a wildlife biologist?

The tennis court activity is based on a 2018 study conducted by Australian wildlife biologist Jarrod Hodgson and colleagues who used plastic duck decoys as models to determine if drones provided more accurate counts for shorebirds than human observers. In that study, observers were at least 37 meters from the closest rubber duck and were standing at the best vantage point possible. To simulate real ground counts, observers were allowed to use binoculars. For the aerial images, Dr. Hodgson's team took images from 30, 60, 90 and 120 meters above the ground. They found flights lower than 90 meters did not provide better counts. When comparing counts from the ground with the counts from the aerial imagery, the aerial images were 43%–96% more accurate.

How did your findings compare to those of Dr. Hodgson?

Drone Use for Other Wildlife Populations

Using drones has been found to be beneficial in research of wildlife other than shorebirds. Studies describing the methods include:

- White-tailed Deer Counts Using Thermal Cameras on sUAV (Beaver et al. 2020).
- Hippopotamus Counts and Aging from sUAV (Inman et al. 2019).

References and Supplemental Information

Barr, J. R., M. C. Green, S. J. DeMaso, and T. B. Hardy. 2020. "Drone Surveys Do Not Increase Colony-wide Flight Behaviour at Waterbird Nesting Sites, But Sensitivity Varies Among Species." *Scientific Reports* 10: 3781. https://doi.org/10.1038/s41598-020-60543-z.

Beaver, J. T., R. W. Baldwin, M. Messinger, C. H. Newbolt, S. S. Ditchkoff, M. R. Silman. 2020. "Evaluating the Use of Drones Equipped with Thermal Sensors as an Effective Method for Estimating Wildlife." *Wildlife Society Bulletin* 44: 434–443.

Hamilton, G., E. Corcoran, S. Denman, M. E. Hennekam, L. P. Koh. 2020. “When You Can’t See the Koalas for the Trees: Using Drones and Machine Learning in Complex Environments.” *Biological Conservation* 247: 108598. https://doi.org/10.1016/j.biocon.2020.108598.

Hodgson, J. C., R. Mott, S. Baylis, T. T. Pham, S. Wotherspoon, A. D. Kilpatrick, R. R. Segaran, I. Reid, A. Terauds, and L. P. Koh. 2018. “Drones Count Wildlife More Accurately and Precisely than Humans.” *Methods in Ecology and Evolution* 9: 1160–1167. https://doi.org/10.1111/2041-210X.12974.

Inman V. L., R. T. Kingsford, M. J. Chase, K. E. A. Leggett. 2019. “Drone-based Effective Counting and Ageing of Hippopotamus (*Hippopotamus amphibius*) in the Okavango Delta in Botswana.” *PLoS ONE* 14(12): e0219652. https://doi.org/10.1371/journal.pone.0219652.

Sasse, D. B. 2003. “Job Related Mortality of Wildlife Workers in the United States 1937–2000.” *Wildlife Society Bulletin* 31(4):1000–1003.

Vas, E., A. Lescroël, O. Duriez, G. Boguszewski, and D. Grémillet. 2015. “Approaching Birds with Drones: First Experiments and Ethical Guidelines.” *Biology Letters* 11(2). Royal Society Publishing. https://royalsocietypublishing.org/doi/pdf/10.1098/rsbl.2014.0754.

Websites

- Great Backyard Bird Count (https://www.birdcount.org/).
- FrogWatch (https://frogwatch.next.fieldscope.org/).

Vendors

(Note: We do not endorse these vendors. They are provided solely for information.)

- Drones devoted to wildlife counting can be found on the Airborne Drones website (https://www.airbornedrones.co/wildlife-and-game/).
- Plastic duck decoys can be found on the Alibaba website (https://www.outdoorlife.com/photos/gallery/hunting/turkey-waterfowl/waterfowl-techniques/2012/08/how-make-your-own-decoys/).

Discussion Questions

Could drones scare wildlife? Would birds think they were hawks or other predators?

- Students might make the connection that wildlife, especially shorebirds, might perceive drones as a predator. The type of drone used (fig. 48) and how it is flown could make a difference.
    - What might be the advantages and disadvantages of using a quadcopter-style drone (small quadcopter) to count wildlife?
    - What might be some advantages and disadvantages of using a fixed-wing drone (small airplane) to count wildlife?
    - What might be the advantages and disadvantages of operating a drone faster or slower over wildlife?
    - What might be the advantages and disadvantages of using a different approach angle to count wildlife?
    - Could the color and/or size of the aircraft have an impact on wildlife disturbance? How?

Figure 48: Quadcopter SkyFish M4 and fixed-wing Sensefly eBee drones. (Photos provided by SkyFish and Sensefly.)

- Barr et al. (2020) found that drones did not significantly increase nesting shorebirds' escape behavior of flying off. However, some species such as laughing gulls were more sensitive to drones. Their research suggests that overall, wildlife is not impacted by drones, but some species could be more aware of the overhead aircraft.

- Vas et al. (2015) found that birds seem to care more about approach angle than the shape of the aircraft.

Table 3. Sample Data Sheet

Student Name or Group Number	Ground Count	Aerial Count	Actual Number	Best Method

Notes:

Activity 6: Mapping Invasive Species

Invasive plant species can wreak havoc on native ecosystems and agricultural areas. Managing these species is particularly time intensive as they often go unnoticed until they have established a population. In this activity, students will map invasive species on school grounds or local natural areas using drones and compare their distributions from past years.

Goal and Objectives

Goal

Students will map invasive species using a drone and compare their results to previous years to determine if invasive plants are spreading. After researching different invasive species, students will determine which species could have the greatest negative impact on their school grounds or local natural area.

Objectives

Students will:

1. Define invasive species.
2. List five invasive species that could be growing on their school grounds or local natural area.
3. List two negative impacts invasive species have on ecosystems and humans.
4. Use aerial imagery to map visible invasive species.
5. Evaluate maps from previous years to determine if select invasive species are spreading.
6. Report which invasive species could have the greatest negative impact on their school grounds or other area being studied.
7. Develop a plan to limit the spread of invasive species on the study area.

Materials

- Student log (e.g., notebook, laptop, data sheet, or other item to record data).
- Drone with FPV camera (ensure camera gimbal can point straight down).
- A guide to invasive species, such as the Plant Invaders of Mid-Atlantic Nature Area (https://www.invasive.org/eastern/midatlantic/).
- A study area with invasive species such as Bradford pear trees. (Please ensure you have permission to fly over the area from the property owner and adhere to FAA regulations.)

Background

Ecosystems are often composed of hundreds of different species of plants and animals that exist in a balance that has been established through natural selection for millions of years. However, humans have, both intentionally and unintentionally, moved many species across the planet, which can cause disruptions in that natural balance.

- How would you define an invasive species?

The Virginia Department of Conservation and Recreation (DCR) defines invasive species as "species intentionally or accidentally introduced by human activity into a region in which they did not evolve and cause harm to natural resources, economic activity or humans." Not all species of plants that have been introduced to the United States become invasive. In fact, we depend on many of these introduced species for food. This website provides a great resource to identify the location of where many plants we grow and use in the United States originated: https://www.thoughtco.com/plant-domestication-table-dates-places-170638. You can learn more about invasive species from the USDA's National Invasive Species Information Center website, (https://www.invasivespeciesinfo.gov/what-are-invasive-species).

- Name five species of introduced plants that are often consumed daily by humans.

Over 50,000 nonnative species (plants, animals, and microbes) have been introduced into the United States. Invasive species often spread rapidly and cause over $137 billion of damage annually (Pimental et al. 2000). These rapidly spreading species often outcompete native plants. Since most wildlife species depend on native plants, invasive plant species often negatively impact our native wildlife. The U.S. Forest Service (n.d.) reports that invasive species have caused the decline of 42% of U.S. endangered and threatened species. Furthermore, invasive species are the leading cause of decline for 18% of U.S. protected species. Review [Multivariate analysis of invasive plant species distributions in southern US forests](https://www.srs.fs.usda.gov/pubs/ja/2021/ja_2021_lucardi_001.pdf) (https://www.srs.fs.usda.gov/pubs/ja/2021/ja_2021_lucardi_001.pdf). Invasive species can be devastating: The brown tree snake in Guam is responsible for causing the extinction of half of the species of birds, several species of lizards, and two of three bat species native to the island (Rodda and Savidge 2007).

More than 90 species of invasive plants have been deemed as threatening or potentially threatening to natural and agricultural lands in Virginia. Review the [DCR's Invasive Plant List online](https://www.dcr.virginia.gov/natural-heritage/invsppdflist) (https://www.dcr.virginia.gov/natural-heritage/invsppdflist). Do you recognize any species on the list? Are they growing in your neighborhood? Review the distribution maps of invasive species on the [EDD Maps website](https://www.eddmaps.org/distribution/) (https://www.eddmaps.org/distribution/).

- List three invasive plant species that have been mapped growing near your school or neighborhood.

- What invasive ranking is assigned to each of these plant species? Are any highly invasive?

Many of Virginia's invasive species have become household names due to their abundance throughout the state. Kudzu (*Pueraria montana* and others in the same genus) is known as "the vine that ate the South." These groups of vines were imported in the late 1800s and were readily planted in the early 1900s to control erosion. Landowners were encouraged and even paid to plant kudzu on their properties. The vines, which can grow more than 12 inches per day, performed their task but spread quickly, covering everything they contacted. Land managers now work desperately to control the vine. Goats have even been used to eat the vines and stop their spread.

Another invasive species found growing throughout Virginia is the Bradford pear tree, a cultivar of the Callery pear (*Pyrus calleryana*) (fig. 49). Many homeowners and developers have planted these trees throughout the state. Bradford pears had several characteristics that made them ideal for homeowners. They were thought to grow 30–35 feet tall but many specimens can reach 50 feet. Their unexpected heights can reach overhead utility lines or exceed heights homeowners are uncomfortable having next to their house, thus requiring require removal. Due to their quick growth and branching structure, the trees are weak and often damaged or destroyed during storms, leaving homeowners with property damage and clean-ups. Bradford pears were also planted for their spring beauty. These trees are covered with white flowers early in the spring before most other native trees flower. Some naturalists have even referred to them as "lighting up as light bulbs." However, many people consider the flowers' aroma to smell like rotting fish, and many allergy sufferers report having issues with Bradford pears. These trees also produce seeds quickly, in as little as three to five years. Many birds, especially the nonnative European starling, consume Bradford pear fruit and then distribute their seeds to adjacent areas. Abandoned or undeveloped lots in neighborhoods quickly are overtaken with Bradford pear trees that outcompete many other plant species.

Figure 49: The Callery (Bradford) pear tree. (Photo by Virginia Tech, Department of Forest Resources and Environmental Conservation.)

Some nonnative plants were originally introduced to benefit wildlife. Once established, these beneficial plants quickly became invasive and are negatively impacting ecosystems. One example is the Autumn olive shrub (*Elaeagnus umbellate*) which can fix nitrogen (add nitrogen to the soil), thus providing its own fertilizer for adapting to poor soil conditions. It produces edible berries that are distributed by birds and many other species of wildlife, spreading quickly, especially into open, dry areas. In addition to benefiting wildlife, this invasive shrub was also used to reclaim mine lands and other eroded areas due to its habit of forming dense stands. These dense stands block light from reaching other plants, creating monoculture stands of Autumn olive (fig. 50). Monoculture stands of any species often do not provide a diversity of food and habitat types that many wildlife species require.

Figure 50: Autumn olive shrubs dominating the landscape. (Photo by Virginia Tech, Department of Forest Resources and Environmental Conservation.)

Some species are introduced intentionally because of their beauty. The princess tree (*Paulownia tomentosa*) was brought to the United States in the 1840s as an ornamental to bring color to the landscape. In the spring, its lilac blue flowers dot the landscape (fig. 51). However, this species quickly establishes in natural areas. It can often be found growing along roadways and forest edges, and can grow 15 feet each year, quickly shading out other species, and producing large quantities of seeds. Princess trees are not as invasive as Bradford pears and autumn olive, but they continue to spread throughout the southeastern United States.

Figure 51: Princess tree blooming in the spring. (Photo by Virginia Tech, Department of Forest Resources and Environmental Conservation.)

- List two negative impacts invasive species have on ecosystems and humans.
- Once established, how are Bradford pears and autumn olive spreading?
- What would have been the easiest way to prevent their spread?
- List a few methods that land managers might use to control kudzu, Bradford pears, or autumn olive.

Many states and local governments have banned the planting of invasive species. One of the easiest methods to stop the spread of invasive species is to never plant them. Virginia has passed legislation, House Joint Resolution No. 527 (https://lis.virginia.gov/cgi-bin/legp604.exe?212+ful+HJ527ER), to request the Department of Conservation and Recreation work jointly with the Virginia Department of Agriculture and Consumer Services to study the sale and use of invasive plant species.

Other invasive plants are quickly becoming a major issue for landowners and ecosystems. When these species are first introduced, they undergo a “lag time,” typically 20 to 100 years, as they adapt to environmental conditions before being recognized as invasive. Some scientists believe that the changing climate could make the dormant invasive species much more aggressive (Clements and Ditommaso 2011). Japanese stiltgrass (*Microstegium vimineum*) was introduced in the 1920s but has recently expanded its range and is threatening ecosystems. The next invader that will become invasive could be inconspicuously growing in our yards, parks, and school grounds right now.

- List one impact climate change might have on invasive species.
- What could be the next species to emerge from its lag time?

Instructional Procedures

Learning Activity: Mapping invasive plants using drones.

Methods

- Teachers and students will identify a location (e.g., school campus, park, or natural area) that is impacted by invasive plant species.
- Students will use drones to identify invasive species that could be or are growing in the study area. Note: This activity should ideally be conducted in early spring when trees and shrubs are blooming and are more easily identified.
- Students will research local invasive species to learn about their natural history.

1. Have students research invasive species for your county or region. You might consider a Zoom session with an expert from Department of Conservation and Recreation (DCR), Natural Resources Commission (NRC), Master Naturalists, local government (e.g., Department of Parks and Recreation), or others to discuss invasive species.
2. Identify an area to map: Your school grounds would be a great location for mapping. However, many local natural areas such as parks, conservation easements, or greenways could benefit from this project. The project could develop into a case-based, service-learning project to help local land managers. Contact your local planning department, Master Naturalist Program (http://www.virginiamasternaturalist.org/), local DCR office (https://www.virginia.gov/agencies/virginia-department-of-conservation-and-recreation/), or local parks and recreation department to locate a potential location for mapping.
3. Conduct drone flights over the area and take pictures to examine for invasive species. Please ensure your chosen location is away from major roads, in approved airspace, and can be flown following all FAA and local regulations. Follow all safety and FAA regulations for drone flights.
4. Count and map specimens of invasive species such as Bradford pear, autumn olive, and princess tree, which are easily visible from aerial images when they are blooming in early spring. Record the information in a logbook, on a data sheet such as the one provided in table 4 (located at the end of this activity), or in another way.
5. Optional: Count the total number of all trees and shrubs in the images to calculate the percentage that are classified as invasive on the property.
6. If images exist from previous years, students can compare numbers to determine the rate of spread for each species, including the number of trees and the percentage of the canopy dominated by the species. Your local government might have aerial images from previous years that could be provided to students, or Google Earth might have images from previous years that students could use to identify and count invasive trees. The likelihood of older images being taken at the same altitude as new imagery would be unlikely. Therefore, we would recommend a relative comparison. Student could use paper or digital versions of imagery and draw circles around each tree species. Next, students would measure the diameter of the circle and calculate the areas of the tree. Native species would be added as would non-native species. The total areas would be the two values combined. The relative frequency would be calculated by diving the total areas of the non-native species by the total canopy area. As new imagery is flown in subsequent years, comparisons can be made to determine with the non-native species is growing in density.
7. If the area flown is large, it could be divided into regions, and students assigned a region to identify and/or count invasive species.
8. Based on their research, students could draft a plan to remove or stop the spread of the invasive species mapped. Students could present their plan to the stakeholders of the property mapped.

Example Imagery of Bradford Pear

Examine the image below (https://tinyurl.com/HP-bradpear), figure 52. Researchers collected imagery in Blacksburg, Virginia, to identify Bradford pear, an invasive species.

- Can you identify any potential Bradford pear trees in the image?
- If so, how many?
- What other information can you gather from this imagery (season, type of vegetation cover, etc.)?

Figure 52: Drone image of Bradford pear trees scattered around a larger tree. (Photo by Virginia Tech's Department of Forest Resources and Environmental Conservation.)

References and Supplemental Information

Clements, D. R. and A. DiTommaso. 2011. "Climate Change and Weed Adaptation: Can Evolution of Invasive Plants Lead to Greater Range Expansion Than Forecasted?" *Weed Research* 51: 227–240.

Pimental, D., L. Lach, R. Zuniga, and D. Morrison. 2000. "Environmental and Economic Costs of Nonindigenous Species in the United States." *BioScience* 50: 1 53-65. https://doi.org/10.1641/0006-3568(2000)050[0053:EAECON]2.3.CO;2.

Rodda, G. H. and J. A. Savidge. 2007. "Biology and Impacts of Pacific Island Invasive Species. 2. *Boiga irregularis*, the Brown Tree Snake (Reptilia: Colubridae)." *Pacific Science*, 61: 307-324. https://doi.org/10.2984/1534-6188(2007)61[307:BAIOPI]2.0.CO;2.

U.S. Forest Service. (n.d.). Invasive Plants: https://www.fs.usda.gov/wildflowers/invasives/index.shtml.

Websites

- Invasive Plants by the U.S. Forest Service provides excellent online learning kits: https://www.fs.usda.gov/wildflowers/invasives/index.shtml.
- The Nature Conservancy – Kudzu: https://www.nature.org/en-us/about-us/where-we-work/united-states/indiana/stories-in-indiana/kudzu-invasive-species/.
- The Washington Post – Bradford Pears: https://www.washingtonpost.com/lifestyle/magazine/how-we-turned-the-bradford-pear-into-a-monster/2018/09/14/f29c8f68-91b6-11e8-b769-e3fff17f0689_story.html.
- Blue Ridge Partnership for Regional Invasive Species Management – Bradford Pears: https://blueridgeprism.org/factsheets/ – click on "Callery (Bradford) Pear (*Pyrus calleryana*)."
- Virginia Cooperative Extension – Autumn Olive: https://www.pubs.ext.vt.edu/420/420-321/420-321.html.

Discussion Questions

How quickly are the trees you mapped spreading?

- Students could compare previous images captured by the local, state, or federal government (or Google Earth) or images captured from previous drone flights to determine the rate of spread for the invasive trees.

What would be the best method to control the invasive species you mapped?

- There are many options that are often species specific. Some methods include mechanical mowing, manual cutting, herbicides, and fire management.

Table 4. Sample Data Sheet: Invasive Species

Property Location (address): ______________________________

Location coordinates of the property

- **Latitude:** ______________________
- **Longitude:** ______________________

Aerial Tree Counts	Current Year Date: __________	Previous Year Date: __________	Percent Change
Total Number of All Species			
Invasive Species #1			
Invasive Species #2			
Invasive Species #3			
Invasive Species #4			
Invasive Species #5			

Notes:

Appendices

Glossary: Learn the Lingo

Area of Operation (AO) – The area in which the drone will be flown.

Beyond Visual Line of Sight (BVLOS) – When drones are no longer within sight of the RPIC, then they are BVLOS. BVLOS can occur when a drone operates too far away to be seen, or if it is obscured by a structure, tree or other object. Under FAA regulations, drones must remain within the RPIC's visual line of sight.

Census – An official count or survey of a population. A census is conducted to get an estimate of a population number. In the U.S, a census on people is completed every 10 years. A periodic census of wildlife is vital to help manage wildlife populations. Conducting an accurate census is therefore a vital management tool.

Federal Aviation Administration (FAA) –The government agency that is mandated to regulate all aspects of civil aviation operating in the national airspace. The FAA is therefore in charge of regulating both crewed and uncrewed aircraft.

First Person View (FPV) – Describes a style of drone operation in which the pilot views the flight through the lens of a camera that is mounted on the drone. FPV does not take the place of visual line of sight.

Fixed-wing Aircraft – An aircraft with two wings attached to the body that do not provide power for thrust. Fixed-wing aircraft typically require an airstrip for landing. An airplane is an example of a fixed-wing aircraft.

Lithium Polymer (LiPo) Battery – This type of battery is used to power drones. LiPo batteries require careful handling because they can be flammable. For example, these batteries should not be used if they are swollen; they should be safely stored in LiPo bags; they shouldn't be stored in conditions that are too hot or too cold, etc.

Multi-rotor Aircraft – An aircraft that uses multiple rotors (as opposed to wings) to generate lift. Examples of muli-rotor aircraft include: a quad copter (four rotors), hexacopter (six rotors), or an octocopter (eight rotors). A helicopter is not considered to be a multirotor copter since it has only one lift generating rotor.

Notices to Air Missions (NOTAMs) – Notices that provide essential information to pilots and other individuals concerned with flight operations in the national airspace system. For most drone pilots, a NOTAM may include temporary or permanent updates that can impact the safe operation of aircraft. Examples of NOTAMs include restricted airspace due to airshows, football games, or the presence of VIPs (often government officials).

Part 107 – Refers to 14 CFR Part 107 Small Unmanned Aircraft Systems, established by the FAA in 2016. This rule establishes requirements for commercial drone operators. It can be found on the National Archives Code of Federal Regulations web page (https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-107#part-107).

Phenology –The study of cyclic and seasonal phenomena. These natural and cyclical patterns are often associated with climate, local weather patterns, and the evolutionary responses of plants and animals to these patterns and cycles.

Remote Pilot Certificate (RPC) – This certificate is administered by the FAA. The FAA requires pilots who operate a drone for commercial purposes to acquire an RPC to ensure that pilots conform to the knowledge and safety procedures and protocols that accompany the operation of a small uncrewed aircraft system (drone).

Remote Pilot in Command (RPIC) – The RPIC is the individual responsible and the final authority for the safe operation of a drone. The buck stops at the RPIC.

Small Uncrewed Aircraft System (sUAS) – As defined by the Federal Aviation Administration, an sUAS is any uncrewed aircraft that can be flown remotely and weighs less than 55 pounds.

Temporary Flight Restrictions (TFRs) – TFRs restrict flights from operating without permission. They are communicated to drone pilots through Notice to Air Missions (NOTAMs).

Tree Canopy – The part of the tree that is above ground. The term is often used to refer to the crown of the tree.

Uncrewed Aerial Vehicle (UAV) – A UAV refers to only the aircraft (the drone itself), not the other components that comprise the system.

Uncrewed Aircraft System (UAS) – An uncrewed aircraft and any supporting equipment (control station, sensors, navigation equipment, etc.).

Visual Line of Sight (VLOS) – VLOS refers to the visibility of the drone by the RPIC. The RPIC must always keep the drone within his or her line of sight. This is stipulated under Part 107.

Glossary: Learn the Acronyms

AGL – Above Ground Level (measured in feet, meters, etc.).

BVLOS – Beyond Visual Line of Sight

LiPo – Lithium Polymer

FAA – Federal Aviation Administration

FPV – First-Person View

NOTAM – Notices to Air Missions

RPC – Remote Pilot Certificate

RPIC – Remote Pilot in Command

UAS – Uncrewed Aircraft System.

sUAS – Small Uncrewed Aircraft System

UAV – Uncrewed Aircraft Vehicle

VLOS – Visual Line of Sight

About the Authors

Kevin Hamed, Ph.D., serves as Collegiate Associate Professor of Wildlife Conservation in the Department of Fish and Wildlife Conservation at Virginia Tech. He is an 20-year veteran of higher education and strives to engage students of all ages in hands-on learning activities to explore our natural world. Throughout his career, he has collaborated with grade K-12 teachers and students to provide case-based experiential learning opportunities focused on fish and wildlife conservation. Kevin has been an active participant in GeoTEd-UAS since 2013. He has an FAA Part 107 Remote Pilot Certificate and has taught numerous classes to prepare students and professionals for their Part 107 exam and primary flights. Kevin's research focuses on Southern Appalachian vertebrates, where he incorporates sUAS to collect data necessary to answer conservation questions. He was the 2009 recipient of the Virginia Professor of the Year award from the Council for the Advancement and Support of Education and the 2017 recipient of the Outstanding Faculty Award from the State Council of Higher Education in Virginia.

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She has 13 years of experience teaching grades 6-12. Veronica has an FAA Part 107 Remote Pilot Certificate and has been involved in sUAS operations since 2014. She has led multiple flight operations including the first UAS operations over Virginia Tech's Lane Stadium as part of a service-learning project. She served as the remote pilot in command of the mission and coordinated all mission requirements, planning with Virginia Tech's safety office. In the summer of 2019, Veronica served as a Master Teacher for Virginia Space Coast Scholars, where she developed and delivered sUAS lessons for students attending the Summer Institute. Veronica served on the 2021 VDOE curriculum review committee for developing statewide curriculum standards for sUAS courses for Career and Technology Education in Technology Education. In 2019, Veronica took the Blacksburg Drone Competition team to Dallas, Texas, where the team placed first in the Bell Vertical Robotics Competition.

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John McGee, Ph.D. is a faculty member in Virginia Tech's Department of Forest Resources and Environmental Conservation and has served as the Virginia Geospatial Extension Program specialist since 2003. Through the VGEP, John has hosted hundreds of geospatial workshops in response to the geospatial educational needs of Virginia's communities. John serves as a co-principal investigator on the National Science Foundation-funded Geospatial Technician Education-Unmanned Aircraft Systems (GeoTEd-UAS) project and is the state coordinator for VirginiaView. He is the co-author of several textbooks on the use of GIS and remote sensing, and provides video tutorials that have been watch online over 14,000 hours. John has actively served to facilitate geospatial-related initiatives and projects since across Virginia since 2003.

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