Student Scholarship Submission

The Importance of Understanding Plant Health and Remote Sensing's Role in Providing the Information for Proper Management

Aaron L. Wood

Department of Space Studies
American Military University

Abstract

The health of the environment starts with the vegetation that resides within the many ecosystems of the planet and the steps necessary to manage their health. Researchers are required to maintain long-term monitoring data that stretches across varying habitats and the different types of plants that make them up. Over the last two to three decades the technologies of remote sensing—the practice of observing and collecting data on an object or region on the Earth's surface—has played a crucial role in assisting habitat managers and policymakers, providing them with necessary information to make informed decisions on how to maintain a healthy and thriving ecosystem. Passive and active sensors, both on airborne and satellite platforms, have obtained a wealth of long-term imagery for these monitoring operations. Without healthy and sustainable plant life, not only will the regional ecosystem and the inhabitants living within it suffer, but so could the entire world. Wetlands, forests, farmland, and grasslands all serve many purposes in the well-being of the environment and the people who depend on them for their resources. This paper outlines these areas of interest and the need for proper management of the health of these plants and their environments.

Keywords: remote sensing, ecosystem, vegetation, satellites

doi: 10.18278/sesa.6.1.2

La importancia de comprender la salud de las plantas y el papel de la teledetección en el suministro de información para una gestión adecuada

Resumen

La salud del medio ambiente comienza con la vegetación que reside en los numerosos ecosistemas del planeta y las medidas necesarias para gestionarla. Los investigadores deben mantener datos de monitoreo a largo plazo que abarcan diversos hábitats y los diferentes tipos de plantas que los componen. Durante las últimas dos o tres décadas, las tecnologías de teledetección —la práctica de observar y recopilar datos sobre un objeto o región de la superficie terrestre— han desempeñado un papel crucial para ayudar a los administradores de hábitats y a los responsables políticos, proporcionándoles la información necesaria para tomar decisiones informadas sobre cómo mantener un ecosistema sano y próspero. Los sensores pasivos y activos, tanto en plataformas aéreas como satelitales, han obtenido una gran cantidad de imágenes a largo plazo para estas operaciones de monitoreo. Sin una vida vegetal sana y sostenible, no solo sufrirá el ecosistema regional y sus habitantes, sino también el mundo entero. Los humedales, los bosques, las tierras de cultivo y los pastizales cumplen múltiples funciones para el bienestar del medio ambiente y de las personas que dependen de ellos para obtener sus recursos. En este artículo se describen estas áreas de interés y la necesidad de una gestión adecuada de la salud de estas plantas y sus entornos.

Palabras clave: teledetección, ecosistema, vegetación, satélites

了解植物健康状况的重要性以及遥感技术在提供正确管理信息方面的作用

摘要

环境健康始于地球上众多生态系统中的植被，以及管理这些植被健康所需的各项措施。研究人员需要维护那些涵盖不同生境及其植物类型的长期监测数据。过去二三十年，遥感技术——即观测和收集地球表面物体或区域数据的技术——在协助生境管理者和政策制定者方面发挥了至关重要的作用，为他们提供了必要的信息，以便就如何维护健康繁荣的生态系统作出明智的决策。被动式和主动式传感器（无论是在机载平台还是卫星平台上）都已获取了大量用于这些监测工作

的长期影像。如果没有健康且可持续的植物生命，不仅区域生态系统及其居民会遭受损失，整个世界也可能受到影响。湿地、森林、农田和草原在环境福祉以及依赖它们获取资源的人们的福祉方面都发挥着多种作用。本文概述了这些研究领域，并强调了“妥善管理这些植物及其生长环境健康”一事的重要性。

关键词：遥感，生态系统，植被，卫星

Introduction

All fauna on Earth require oxygen to breathe in order to survive. The plants that grow on this planet provide this oxygen as a byproduct of a process known as photosynthesis, where energy is harvested from sunlight and carbon dioxide is absorbed from the atmosphere by plants and then converted into soluble carbohydrates for the plant's continued growth (Dey et al., 2021 and Shackira et al., 2022). Without this oxygen, life on this planet that draws breath to live would not exist. The importance of maintaining strong, healthy flora stretches beyond the need to take in oxygen to survive. There are a number of other important roles that plants play in this world. The crops that are grown all over the world are consumed as part of an essential diet by humans and other animals, the many different species of trees in the forests provide shelter to the animals that call these forests their home and provide lumber for houses for humans as well, and aquatic vegetation, such as algae, help keep the waters of this planet clean and oxygenated (Campbell & Wynne, 2011). Without all these varying plant species, key processes—such as regulating the global carbon cycle to maintain an equilibrium of the Earth's climate—would cease to exist (Jarvis et al., 2001). Monitoring and maintaining the health of the plant life is essential to the continued health of everything that calls Earth home, including the Earth itself. Scientists and researchers perform tasks of tracking Earth's flora with many different forms of remote sensing, the technology and technique designed to image large geographical areas in a shorter amount of time than more traditional *in situ* forms of data acquisition.

Remote sensing is the gathering of information about an object or geographical area from a distance by use of sensors that detect energy within the electromagnetic spectrum via aircraft or spacecraft (Campbell & Wynne, 2011). This allows for a much larger area of coverage for data collection in a shorter amount of time than direct, physical collection during *in situ* activities. Direct, hands-on collection may involve a single individual or a team of technicians working for extended periods of time, ranging from hours to days to weeks, operating numerous different devices to gather information on plant coverage, species identification, photographs, soil condition measurements, etc. that either an airborne or satellite remote sensing platform could do in minutes to hours. Aircraft are desirable for regional coverage, as they are cheaper to operate than space-based platforms and can be operational and on-site when needed. Aircraft can make multiple passes over the same area, on the same day, in case the first pass is suspected to have insufficient results. Satellites, however, can cover a greater geographical area and can be utilized by a much larger group of researchers, due to their location, orbiting the Earth. As opposed to a team of individuals in a field, one satellite can make observations that can later be analyzed for many different points of concern, the same as those listed for *in situ* collections. This paper will examine the mission objectives and planning, sensor technologies, and vegetation of varying ecosystems, along with direct, contributing factors required for a better understanding of remote sensing applications, such as data processing, soil conditions, and water resources, all of which hold importance to the study of Earth's plant life.

Mission Objective

The study of vegetation has long been of importance to society. As humans expanded across the globe, learning which plants are safe to eat, which ones are most useful for building homes and tools, and what they can tell us about the area, they have established communities and thrived. Plants have been used as indicators to gauge the environmental health of regions, as they can inform individuals of quality lands for agriculture, safe places to live, and the potential for potable water (Kollmann & Fischer, 2003). From the trial-and-error observation methods used centuries ago, the study of plants has evolved to the use of remote sensing systems such as air and spacecraft. The primary goal of vegetation observations and research operations is to better understand the past, current, and future state of the region under study. These studies can range from crop production to disease tracking. Ultimately, observers want to be able to obtain data to support future policy decisions, whether that's the planting of particular crops the next season for, or allowing forestry services to authorize harvesting trees for lumber (Campbell & Wynne, 2011).

Regardless of the operation, proper mission planning is essential for a safe and successful outcome, and the decisions about how to acquire the appropriate data depends on the type of study being conducted. Without the proper data acquisition platform or sensor system, the success of the mission is in jeopardy. What time of the year the observations be taken? Will the observations neccesarily be taken during a specific period, regardless of weather conditions? How large of an area is under study? Will the study require photographs, and if so, will panchromatic be sufficient or will color be needed? These and many other questions must all be considered when planning and preparing for any research project. In this paper, we will be looking at remote sensing observations form aircraft and satellite systems and how they are applied to different situations.

Airborne Platforms

Airborne platforms, such as airplanes, balloons, and kites, have all been used at some time or another for remote sensing of vegetation all over the globe. Whether these observations are just images of an area, or they are intended for a much more scientific purpose, airborne remote sensing plays a vital role in regional vegetation monitoring. The use of aircraft for vegetation studies has shown to be a better option than satellites for smaller, regional studies conducted by either county-level or state-level organizations. The costs associated with the use of a satellite might be out of the budget for localized observations of tree coverage of a state park or the monitoring of crops of agricultural operations (Campbell & Wynne, 2011). The categories of airborne remote sensing platforms can be broken down into two types: manned and unmanned.

Manned airborne platforms, primarily airplanes, have been utilized to capture much higher spatial resolution images—2.5 cm as compared to the 30 cm resolution provided by the Worldview4 satellite—which is the orbiting system with the highest resolution imagery commercially available (Hollings et al., 2018) for surveys and land observations. When satellite observation is not available, yet larger areas still need to be imaged, manned aerial systems have a greater ability to cover these larger areas than unmanned aerial systems (UAS) (Wang et al., 2019). Observing land cover and vegetation from a manned light aircraft allows for the potential of multiple observers scanning the area that is being flown over. UASs only allow for imaging to be taken by the onboard photography system, whereas the personnel inside the aircraft, possibly two in a light aircraft such as a small plane or helicopter, have the ability to scan the land visually and make onboard decisions if another pass may be needed to catch something that may have been missed on the initial pass. There are some benefits to having personnel onboard an airborne observation survey, but there are also many advantages to unmanned surveys as well.

Unmanned operations, carried out by various types of UASs, are fast becoming the platform of choice for aerial remote sensing in vegetation, and other land observation, studies, as compared to manned operations they are generally less expensive and greatly reduce the risk for survey personnel (Wang et al., 2019). Both manned and unmanned aerial imagery platforms have the advantage of being able to customize the sensor system onboard; they are able to have the flights timed when considering the weather; they can measure the time duration between imaging; and they support a faster application of advanced technology (Hollings et al., 2018). Since their introduction to remote sensing, UASs have been applied to the observations of marine fauna (Colfax et al., 2017), as well as animals that live in open areas such as elephants with the use of photographic imagery and thermal infrared sensors for deer and foxes that reside in heavily vegetated areas (Wang et al., 2019), and in agricultural practices (Hunt & Daughtry, 2017). UASs are not only widely being put into use for remote sensing activities, but are also the original remote sensing systems, dating back to 1858 when Tournachon took photographs of Paris from a hot-air balloon and English meteorologist E.D. Archibald utilized kites in 1882. Since that time, three categories of UAS platforms, Medium-Range Endurance to Exo-Stratosferic, close-short-medium-range, and nano-micro-mini have been put into operation, all catering to different functions and conditions. The latter two are more suitable for scientific and commercial research studies of vegetation, as the first is generally operated by the military (Colomina & Molina, 2014).

Satellite Platforms

Earth-observing satellites, once they are in orbit, are a more inexpensive asset for vegetation studies (Wang et al., 2019) than the constant use of airborne platforms. For studies taking place in large areas, such as the prairie grasslands of North America, Landsat, one of the primary satellite systems for land observations, orbits the Earth in a sun-synchronous orbit, traveling from north to south, viewing the sunlit side of the Earth, allowing it to take images of the planet's surface (Guo et al., 2005). Figure 1, below, illustrates the north-to-south orbital track of a sun-synchronous satellite, along with key points, such as the perigee (close point to the Earth), apogee (furthest point from the Earth), ascending and descending nodes (where the satellite crosses the equator on its respective north-south orbit), and the inclination (the angle between the orbital track and the equator at the descending node) (Campbell & Wynne, 2011).

Sun-Synchronous Orbit with Key Points

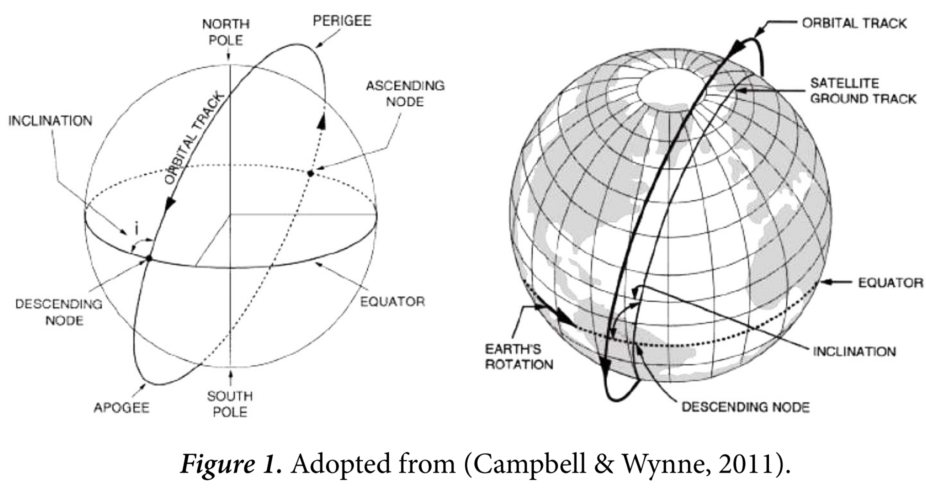

Figure 1. Adopted from (Campbell & Wynne, 2011).

Campbell & Wynne (2011) also point out that for vegetation surveys, photographic imagery is a necessity for an overall understanding of how the plants' growth and coverage progress through the seasons, making the sun-synchronous orbit for remote sensing ideal, allowing satellite systems such as Landsat to observe the same place on the Earth's surface at the same time each day, which is crucial for long-term, continuous studies.

Another advantage of the sun-synchronous orbit, making it desirable for vegetation studies and monitoring, is that it reduces the variations of lighting conditions by synchronizing the orbital track of the satellite to the rotation of the Earth so that it passes over the same ground track at the same time of each successive day (repeat cycle) (Saboori et al., 2014). The *hour angle (h)*, is the angle between the direct solar beam and the point of interest (and respectively, the sensor in orbit), measured with respect to the center of the Earth, and can be calculated with the formula,

$$h = [(GMT - 12.0) * 15] - longitude \quad \text{(Eq. 1)}$$

- GMT = Greenwich Mean Time
- longitude = longitude of the point of interest

With the longitude constantly changing, mission design engineers need to ensure that the satellite orbits the same scene at the same local sun time to maintain an orderly local sun angle (Campbell & Wynne, 2011).

Landsat TM Sensor Parameters and Characteristics

Band	Resolution	Spectral definition	Some applications[a]
1	30 m	Blue-green, 0.45–0.52 µm	Penetration of clear water; bathymetry; mapping of coastal waters; chlorophyll absorption; distinction between coniferous and deciduous vegetation
2	30 m	Green, 0.52–0.60 µm	Records green radiation reflected from healthy vegetation; assesses plant vigor; reflectance from turbid water
3	30 m	Red, 0.63–0.69 µm	Chlorophyll absorption important for plant-type discrimination
4	30 m	Near infrared, 0.76–0.90 µm	Indicator of plant cell structure; biomass; plant vigor; complete absorption by water facilitates delineation of shorelines
5	30 m	Mid infrared, 1.55–1.75 µm	Indicative of vegetation moisture content; soil moisture mapping; differentiating snow from clouds; penetration of thin clouds
6	120 m	Far infrared, 10.4–12.5 µm	Vegetation stress analysis; soil moisture discrimination; thermal mapping; relative brightness temperature; soil moisture; plant heat stress
7	30 m	Mid infrared, 2.08–2.35 µm	Discrimination of rock types; alteration zones for hydrothermal mapping; hydroxyl ion absorption

[a]Sample applications listed here; these are not the only applications.

Table 1. Adopted from (Campbell & Wynne, 2011).

A few of the systems that are in operation for vegetation monitoring are the Landsat Thematic Mapper (TM) and the VEGETATION (VGT) instrument onboard SPOT 4 and SPOT 5. While the TM records in seven spectral bands each with their own applications (Table 1), VGT has a charged-couple device

(CCD) linear array that operates in four spectral bands. VGT's four bands' spectral definitions correspond with bands 1, 3, 4, and 5 respectively (Campbell & Wynne, 2011). All four of these spectral bands are useful for different vegetation scanning, from distinguishing between different plant types to the health of the plants under observation.

Sensor Technology

Regardless of whether the remote sensing platforms are airborne or satellite, there are two different categories of sensor technology: active and passive. The primary difference between the two is that active generates its own energy, and passive detects the energy emitted from the Earth's surface. Each of these two sensor technologies has different advantages and applications when it comes to vegetation studies. The following sections will discuss not only the uses of each of these technologies, but also some of the systems that are in place for each.

Active Microwave Sensors

Active sensors play a vital role in studying vegetation of all different types to determine the growth and health of an ecosystem, from forests to crops. They are especially beneficial on satellite remote sensing platforms. One study has shown that remote sensing methods using Earth observation (EO) satellites equipped with Synthetic Aperture Radar (SAR) are preferred over passive, optical sensors for their ability to penetrate cloud cover, allowing their use regardless of the current weather (Hosseini & Hayne, 2021). This ability allows their use to be scheduled more consistently, as data is able to be obtained from every pass of an area, even if adverse conditions are present, whereas a passive system, using an optical sensor, would not be able to capture images through cloud cover. This can be especially important in times of disaster relief after a hailstorm or hurricane, when analysts would like to know the current conditions of plant life yet the cloud coverage hasn't moved away from the affected area. SAR systems are important for agricultural research as well. One study, conducted by Parag et al. (2024), showed that two SAR systems, RADARSAT-2 and Sentinel-1, were the predominate systems when compared to 13 other SAR sensors that also performed the same function of vegetation biomass studies, and when compared to optical sensor systems, these active sensor systems were found to be more suitable for continuous monitoring as well. Parag et al. (2024) point out that both the RADARSAT-2 and Sentinel-1 SAR satellites offer day and night imaging, multiple polarimetric modes, and a range of incidence angles; however, since it was put into operation in 2014, Sentinel-1 has been utilized more often than RADARSAT-2, due to its shorter revisit time of 12 days, as compared to RADARSAT-2's revisit time of 24 days (cited in Harfenmeister et al., 2021) and its open-access data policy (cited in Khanbbazan et al., 2019).

Post-disaster observation studies are another operation in which active microwave sensors are utilized. SAR satellite images, provided by the International Charter for Space and Major Disasters, have been used to study wind-thrown forests in Sweden, and other European countries, after incredible damage had been caused by devasting storms from 2005 to 2007 (Fransson et al., 2010). While optical imaging can provide high-resolution imaging of effected areas, active radar sensors can provide details that go deeper than the surface cover. Analysts may want to know how these downed trees affect the soil in these areas, and without the ability of radar to penetrate foliage, these readings are only attainable by *in situ* observations.

Passive Optical Sensors

Passive microwave sensors, which are sometimes referred to as optical sensors the electromagnetic radiation energy emitted from the Earth's surface, including vegetation, resulting in panchromatic (black and white; brightness of the radiation within the visible spectrum provides a detailed image without separating the colors), natural-color model (images in the red, green, and blue [RGB]), color infrared model (the blue wavelength band is discarded and a band in the near-infrared [NIR] spectrum is added; green appears as blue; red appears as green; NIR appears as red), and thermal imagery (Campbell & Wynne, 2011). All of these categories of optical imagery serve a purpose in both focused and general-purpose vegetation studies, dependent on the parameters set forth by the research analyst.

The satellite sensors of the Landsat TM and Enhanced Thematic Mapper plus (ETM+), with a 185 km wide swath, its 6 fine resolution channels of 30 meters, a 16-day revisit schedule, and large archive of detailed images dating back decades, provides researchers with a wealth of data to analyze for their particular study, such as the long-term monitoring of the health of the vegetation in four separate national parks of northern Canada, with the addition of the Normalized Difference Vegetation Index (NDVI) (Fraser et al., 2011). One of the most common vegetation indices, the NDVI, when used with Landsat TM data, is calculated as shown in the below equation (Campbell & Wynne, 2011).

$$NDVI = \frac{NIR-R}{NIR+R} = \frac{TM4-TM3}{TM4+TM3} \qquad \text{(Eq. 2)}$$

Passive, optical satellite sensors are desirable because they are cheaper than eddy-covariance measurement methods, which are measurements taken of the carbon, water, and heat flow between vegetation and the atmosphere (Liang et al., 2012); however, they vary greatly in illumination, weather conditions, and sensor noise, but these variations can be minimized by the use of optical sensor systems near the ground (Eklundh et al., 2011). Airborne sensor systems, installed on aircraft, can fly below the cloud cover and is able to obtain the same sun angle across multiple scans of the vegetation under study. The Compact Airborne Spectrographic Imager-1500 is a hyperspectral imager that has been used, in conjunction with the relative spectral responses of current and former multispectral satellite sensors, to analyze such things as submerged aquatic vegetation (Rowan et al., 2021). Passive sensor systems like these, both airborne and space-based, are a vital asset in the surveying of vegetation of all ecosystems, and a necessary resource in the monitoring of plant life around the world.

Plant Categories Observed

The study of vegetation on Earth via remote sensing data has seen tremendous growth in the last two to three decades, due in part to vast quantities of rapidly growing and freely accessible data from both airborne and satellite optical sensors (Kulawardhana et al., 2017). These sensors operate within the visible spectrum (400 to 700 nm) (Pinter Jr. et al., 2003), utilizing electromagnetic energy emitted from the plants on Earth's surface. The green color that is associated with healthy vegetation is due to the way that chlorophyll pigment in plants absorb energy in the red and blue portions (0.6 to 0.7 µm and 0.4 to 0.5 µm, respectively) of the electromagnetic spectrum and how the mesophyll structures reflect the energy in the green and even higher in the near-infrared portions (0.5 to 0.6 µm and 0.72 to 1.30 µm, respectively) (Wu et al., 2023; Singh & Vyas, 2022; Basso et al., 2004; Campbell & Wynne, 2011), allowing for the employment of the NDVI (Eq. 2) to calculate an ecosystem's capability to convert the energy from the Sun into biomass (Wu et al., 2023, cited in An et al., 2013). Being able to capture detailed images of different vegetation and their environments is crucial to the researcher's and policymaker's ability to make informed decisions on the health and productivity of the plant life under observation. Aquatic vegetation, trees in forests, varying crops in a farmer's fields, and grasses in the prairies can inform analysts about the health of the ecological processes in those ecosystems.

Aquatic Vegetation

About 70 percent of the Earth's surface is water, both fresh and marine, and is a major resource for humans and animals alike, providing potable water, food resources, and modes of travel. As with plants of any other ecosystem, the local, submerged aquatic vegetation is essential to the ecological health of bodies of water, as it supplies the local fauna with food and shelter, and all around improves the water quality (Rowan et al., 2022, cited in Hestir et al., 2016). Singh and Vyas (2022) state that "one of the most effective ways to monitor riverine environments, including lakes, channels, reservoirs, floodplains, and wetlands, is to use remote sensing and geographic information systems." The utilization of these two tools provides a crucial source of information mapping that analysts use to study an ecosystem's vegetative health.

Optical remote sensing appears to be the desired method for studying and monitoring aquatic vegetation, including submerged plants (Rowan et al., 2021), as there is a large inventory of ongoing remote sensing imagery in which to apply derived vegetation indices in order to estimate the biomass in various wetlands (Wu et al., 2023). The separation of water and vegetation is distinguished in near-infrared and medium-infrared wavelengths (0.72 to 1.30 and 1.30 to 3.00 μm, respectively) (Campbell & Wynne, 2011), as water primarily absorbs this energy and vegetation reflects a greater amount (Singh & Vyas, 2022). Both Wu et al. (2023) and Singh & Vyas (2022) utilized the Landsat constellation's Thematic Mapper, Enhanced Thematic Mapper Plus, and Operational Land Imager sensors to obtain imagery data, and Wu et al. (2023) also applied Google Earth Engine image services to create their monthly image composites for their studies. Large composite imagery collections, such as those employed in these two studies, are essential for long-term monitoring and accurate vegetation studies.

Crops

A healthy agricultural system is vital for food security for a nation, as well as for a vibrant and productive ecosystem and surrounding environments. Strong, healthy crops can provide not only food resources for humans, but also food and shelter for wildlife and protection from soil erosion that can have a positive impact on the cleanliness of surrounding waterways. The health of agricultural vegetation and the production of crops have direct effects on the health and sustainability of a large part of the globe (Basso et al., 2004), and since as early as 1929, aerial photographs have been used to map crop production and the environment associated with agricultural practices (Basso et al., 2004, cited in Bauer, 1975). Agricultural operations do not plant, grow, and harvest just one type of crop, and there is likely more than one type of crop grown in adjacent fields within a farm. Remote sensing data can provide information on each of those crops, based on a strong understanding of the local vegetation by the analyst studying images taken to monitor crop production and growing processes.

The knowledge of the growth stages of specific crops in a particular region (i.e., the Midwest of the United States) allows farmers and agronomists to develop a crop calendar, which is a timeline that outlines the growth stages of a crop, such as winter wheat (Table 2) and corn (Table 3) in Kansas, to a calendar month. With this knowledge, remote sensing imagery will allow analysts to observe the growth and health of different crops in a single field or image (Campbell & Wynne, 2011).

Management of crop growth, health, and production is important in driving economic and environmental decisions and has been improved upon over the years by utilizing remote sensing imagery of farm crop fields. Ideally, collection of multispectral imagery should be taken early in the day, at the beginning of the growth stage, as the sun angle at this time of the day allows for greater detection of plants in low-leaf stages (Pinter Jr. et al., 2003). Starting at the beginning of the growth stage and continuing through the growing season, surveys of the same crops in the same region can provide the necessary

Crop Calendar for Winter Wheat

September October	Plowing and planting
October November	Emergence and early growth
December January February March	Dormancy
April May	Growth resumes
June July	Heading Harvest
August	

Table 2. Adopted from (Campbell & Wynne, 2011).

Crop Calendar for Corn

April May	Plowing and planting
May June	Emergence and early growth
July	Tasseling
August September	Maturity and harvest

Table 3. Adopted from (Campbell & Wynne, 2011).

data to farmers about when to plant and when to harvest. Long-term monitoring of crop production across multiple seasons can also provide important data on the health of the crop's growth potential from year to year and allow analysts to monitor environmental impacts potentially resulting from the region's agriculture. Further studying of agricultural practices as a whole, not just regionally, is important to maintaining a healthy balance between human interaction (farming the land) and ecosystem responses (negative, positive, or neutral) to those operations.

Forests

Forests are one of the most important ecosystems on the planet. They provide a large amount of oxygen, which is necessary for life, and also act as a major component in absorbing and recycling carbon from the atmosphere. Remote sensing plays an important role in monitoring the health of forests and supplies important data to policymakers, allowing for informed decisions on environmental and industrial practices concerning the use of forest resources. Studying forests is important to environmental health monitoring, but also forestry productivity for timber harvesting operations, and understanding tree diversity may lead to an increased ability for forest management for the timber industry (Mori et al., 2017). Fassnacht et al. (2016) provided a review of over 100 studies that have shown the importance of remote sensing in the classification of different species of trees as it relates to the management of these forests. Spatial information about the tree species over a large area is essential to the understanding of the ecology of forests and the roles that they play in community dynamics within the ecosystem (Fassnacht et al., 2016, cited in Chambers et al., 2013). Species classifications for a number of these studies were obtained by hyperspectral spectroscopy and numerous multispectral resolution systems, such as Landsat and Hyperion (moderate), SPOT and RapidEye (high), and IKONOS (very high), where most of these passive sensors were coupled with active sensor systems (Fassnacht et al., 2016).

Forest fires are a major concern in certain regions of the world, including the southwestern and western United States. Each year they cause tremendous damage to habitats and populated areas, destroying homes and sometimes entire cities (Barmpoutis et al., 2020). One of the biggest concerns when dealing with a forest fire is the safety of those individuals on the ground. Advances in remote sensing technologies, especially in the field of unmanned aerial vehicles (UAVs), and the utilization of "ultra-high resolution optical or infrared charge-coupled (CCD) cameras" have provided a safe means to observe and track, with a greater level of safety and accuracy, the progression of the fire from above (Barmpoutis et al., 2020). While the specially equipped UAVs can survey an active forest fire, preemptive monitoring of the forest floor may assist forest managers in carrying out targeted risk mitigation activities to help prevent these fires from either starting or spreading too rapidly to respond to in a timely manner. Photographs from above the forest may not reveal the debris on the forest floor, which will act as fuel to start and spread fires faster. Lidar and radar sensors provide their own energy source for imaging surfaces of Earth and have the ability to penetrate through crown coverage of trees to observe the forest floor for these types of surveys. SLICER (Scanning Lidar Imager of Canopies by Echo Response) is a lidar (light detection and ranging) sensor system, a form of active sensor, that can be applied to studying the structure of vegetation canopies of trees, which is vital to understanding the physical structure of a forest and has become a proven inventory tool for forest management operations (Campbell & Wynne, 2011). By studying living trees and other vegetation in forests, not only can forest managers determine the health and productivity of a forest for timber harvesting operations, but can also take appropriate actions to maintain and clean up debris-ridden areas that are at potential risk of fire.

Grasslands and Prairies

Grass and prairie lands are the most expansive terrestrial ecosystems in the entire world, covering approximately 30% (Bengtsson et al., 2019) of the planet's landmass, and are a critical food source for various types of livestock (Ali et al., 2016). As with all other ecosystems, the quality and health of the grasses in prairie lands is an indicator of the health and productivity of the local ecology.

Remote sensing, with a focus on grassland management, is utilized for determining and classifying different types of grasses, biomass estimations for the assessment of livestock grazing capacity, pasture and vegetation quality, and vegetation growth rates (Ali et al., 2016).

Grasslands play an important role in the local ecosystems as they affect conditions such as water supply, climate regulation, erosion prevention, livestock for quantity and quality, and crop production in croplands (Bengtsson et al., 2019). Unlike other ecosystems, such as forests and wetlands, the vegetation of the prairie lands is not overbearing to the point of obscuring other plants that analysts wish to study. Landsat's optical imaging sensors, especially, are the primary systems used to study grasslands and monitor their health and productivity, because lidar systems (active microwave sensors) are not suitable for studying and surveying grasslands (Kulawardhana et al., 2017). These systems may not be able to detect centimeter-level differences between different grasses and may not be able to distinguish between vegetation and ground surfaces (Kulawardhana et al., 2017, cited in Bowen & Waltermire, 2002).

Critical Thinking

The application of both passive and active remote sensing sensors for the long-term monitoring of plants across varying ecosystems has been extensively covered in professional research. Depending on the plant life being surveyed, and the studies being conducted, researchers make the decision on which sensor technology to employ, and whether airborne or space-based is more applicable. With the continual advancements in remote sensing technologies and the increase in environmental awareness, planetary sustainability, safety, the well-being of society, and research into the vegetation of ecosystems will continue to increase as well. Data provided from multiple remote sensing platforms, passive and active, and airborne and space-based, will continue to play an important role in monitoring and managing the health of Earth's vegetation. As vast as the planet is, and expansive areas that can be extremely remote and difficult for individuals to physically access, without the capabilities of remote sensing systems, those regions may go unmonitored and managed, which could lead to devasting results.

Conclusion

While there are many different types of ecosystems in the world, all with their own primary types of vegetation, the one thing that is consistent across them all is that all successful monitoring and management of these plants is needed to ensure a healthy ecosystem. Plants in all environments play roles in providing clean and habitable conditions by providing oxygen for growth, shelter for fauna including timber that humans use in their construction of homes, and as a food source. Remote sensing, both active and passive, plays an essential role in proper management of these plants and their regions. With the vastness of these habitats, eddy-covariance and in situ measurements cannot supply researchers and analysts with the proper level of detail or the quantity of data that is needed to perform proper management practices. As it stands today, continued, long-term data collection and monitoring of the planet's vegetation, both great and small, is vital to the continued health of the ecosystems and the sustainability of their production to support human activities.

References

Barmpoutis, P., Papaioannou, P., Dimitropoulos, K., & Grammalidis, N. (2020). A review on early forest fire detection systems using optical remote sensing. *Sensors*, *20*. https://doi.org/10.3390/s20226442

Basso, B., Cammarano, D., & Vita, P. D. (2004). Remotely sensed vegetation indices: Theory and applications for crop management. *Rivista Italiana Di Agrometeorologia*, *1*(5), 36–53.

Bengtsson, J., Bullock, J. M., Egoh, B., Everson, C., Everson, T., O'Connor, T., O'Farrell, P. J., Smith, H. G., & Lindborg, R. (2019). Grasslands—more important for ecosystem services than you might think. *Ecosphere*, *10*(2). https://doi.org/10.1002/ecs2.2582

Campbell, J. B., & Wynne, R. H. (2011). *Introduction to Remote Sensing* (5th ed.). Guilford Press.

Colefax, A. P., Butcher, P. A., & Kelaher, B. P. (2017). The potential for Unmanned Aerial Vehicles (UAV) to conduct marine fauna surveys in place of manned aircraft. *ICES Journal of Marine Science*, *75*(1), 1–8. https://doi.org/10.1093/icesjms/fsx100

Colomina, I., & Molina, P. (2014). Unmanned aerial systems for photogrammetry and remote sensing: A review. *ISPRS Journal of Photogrammetry and Remote Sensing*, *92*, 79–97. https://doi.org/10.1016/j.isprsjprs.2014.02.013

Dey, P., Datta, D., Pattnaik, D., Dash, D., Saha, D., Panda, D., Bhatta, B. B., Parida, S., Mishra,U. N., Chauhan, J., Pandey, H., & Singhal, R. K. (2021). Chapter 5 - Physiological, biochemical, and molecular adaptation mechanisms of photosynthesis and respiration under challenging environments. In *Plant Perspectives to Global Climate Changes: Developing Climate-Resilient Plants*. Essay, Academic Press.

Eklundh, L., Jin, H., Schubert, P., Guzinski, R., & Heliasz, M. (2011). An optical sensor network for vegetation phenology monitoring and satellite data calibration. *Sensors*, *11*, 7678–7709. https://doi.org/10.3390/s110807678

Fassnacht, F. E., Latifi, H., Stereńczak, K., Modzelewska, A., Lefsky, M., Waser, L. T., Straub, C., & Ghosh, A. (2016). Review of studies on tree species classification from remotely sensed data. *Remote Sensing of Environment*, *186*, 64–87. https://doi.org/10.1016/j.rse.2016.08.013

Fransson, J. E. S., Pantze, A., Eriksson, L. E. B., Soja, M. J., & Santoro, M. (2010). Mapping of wind-thrown forests using satellite SAR images. *2010 IEEE International Geoscience and Remote Sensing Symposium*. https://doi.org/10.1109/igarss.2010.5654183

Fraser, R. H., Olthof, I., Carrière, M., Deschamps, A., & Pouliot, D. (2011). Detecting long-term changes to vegetation in northern Canada using the Landsat Satellite Image Archive. *Environmental Research Letters*, *6*. https://doi.org/10.1088/1748-9326/6/4/045502

Guo, X., Zhang, C., Wilmshurst, J. F., & Sissons, R. (2005). Monitoring grassland health with remote sensing approaches. *Prairie Perspectives*, *8*, 11–22.

Hollings, T., Burgman, M., van Andel, M., Gilbert, M., Robinson, T., & Robinson, A. (2018). How do you find the green sheep? A critical review of the use of remotely sensed imagery to detect and count animals. *Methods in Ecology and Evolution*, *9*, 881–892. https://doi.org/10.1111/2041-210x.12973

Hosseini, M., & Haynes, K. (2021, October 25). *Monitoring soil moisture over agricultural fields using synthetic aperture radar*. Earth data for informed agricultural decisions. https://nasaharvest.org/news/monitoring-soil-moisture-over-agricultural-fields-using-synthetic-aperture-radar

Hunt, E. R., & Daughtry, C. S. (2017). What good are unmanned aircraft systems for agricultural remote sensing and precision agriculture? *International Journal of Remote Sensing*, *39*, 5345–5376. https://doi.org/10.1080/01431161.2017.1410300

Jarvis, P. G., Saugier, B., & Schulze, E.-D. (2001). Productivity of boreal forests. *Terrestrial Global Productivity*, 211–244. https://doi.org/10.1016/b978-012505290-0/50011-9

Kollmann, J., & Fischer, A. (2003). Vegetation as indicator for habitat quality. *Basic and Applied Ecology*, *4*(6), 489–491. https://doi.org/10.1078/1439-1791-00209

Kulawardhana, R. W., Popescu, S. C., & Feagin, R. A. (2017). Airborne lidar remote sensing applications in non-forested short stature environments: A review. *Annals of Forest Research*, *60*(1), 173–196. https://doi.org/10.15287/afr.2016.719

Liang, S., Li, X., & Wang, J. (2012). Vegetation production in terrestrial ecosystems. *Advanced Remote Sensing* (pp. 501–531). essay, Academic Press. Retrieved 2024, from https://www.sciencedirect.com/science/article/pii/B9780123859549000162.

Mori, A. S., Lertzman, K. P., & Gustafsson, L. (2017). Biodiversity and ecosystem services in forest ecosystems: A research agenda for Applied Forest Ecology. *Journal of Applied Ecology*, *54*, 12–27. https://doi.org/10.1111/1365-2664.12669

Parag, M., Lottering, R., Peerbhay, K., Agjee, N., & Poona, N. (2024). The use of synthetic aperture radar technology for crop biomass monitoring: A systematic review. *Remote Sensing Applications: Society and Environment*, *33*. https://doi.org/10.1016/j.rsase.2023.101107

Pinter, Jr., P. J., Hatfield, J. L., Schepers, J. S., Barnes, E. M., Moran, M. S., Daughtry, C. S. T., & Upchurch, D. R. (2003). Remote sensing for crop management. *Photogrammetric Engineering and Remote Sensing*, *69*(6), 647–664. https://doi.org/10.14358/pers.69.6.647

Rowan, G. S., Kalacska, M., Inamdar, D., Arroyo-Mora, J. P., & Soffer, R. (2021). Multi-scale spectral separability of submerged aquatic vegetation species in a freshwater ecosystem. *Frontiers in Environmental Science*, *9*. https://doi.org/10.3389/fenvs.2021.760372

Saboori, B., Bidgoli, A. M., & Saboori, B. (2014). Multi-objective optimization in repeating sun-synchronous orbits design for remote-sensing satellites. *Journal of Aerospace Engineering*, *27*. https://doi.org/10.1061/(asce)as.1943-5525.0000340

Shackira, A. M., Sarath, N. G., Aswathi, K. P., Pardha-Saradhi, P., & Puthur, J. T. (2022). Green seed photosynthesis: What is it? What do we know about it? Where to go? *Plant Physiology Reports*, *27*(2). https://doi.org/10.1007/s40502-022-00695-4

Singh, A., & Vyas, V. (2022). A review on remote sensing application in river ecosystem evaluation. *Spatial Information Research*. https://doi.org/10.1007/s41324-022-00470-5

Wang, D., Shao, Q., & Yue, H. (2019). Surveying wild animals from satellites, manned aircraft and Unmanned Aerial Systems (UAS): A Review. *Remote Sensing*, *11*. https://doi.org/10.3390/rs11111308

Wu, W., Grimes, E., & Suir, G. (2023). Impact of freshwater diversions on vegetation in coastal wetlands based on remote sensing derived vegetation index. *Frontiers in Marine Science*. https://doi.org/10.3389/fmars.2023.1202300