Chapter 1
Introduction to Remote Sensing

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OBJECTIVES

Remote sensing is the science of gathering spatial information about the Earth's surface (as well as the oceans and atmosphere) from a distance, using either hand-held, aircraft, or satellite sensors. Such data are routinely used in landscape ecology to map, monitor, and manage landscapes. It is important to understand and fully appreciate the different types of electromagnetic radiation used to create geodata derived from remote sensing systems, the spectral and spatial properties of natural and manufactured materials, as well as the characteristics of airborne and satellite sensor systems. Understanding these fundamental aspects of remote sensing will assist landscape ecologists in understanding and distinguishing the diversity and heterogeneity of land cover types in their study regions and better assess how landscapes might have changed over time. This chapter will enable students to:

1. Understand, explain, and quantify aspects of the electromagnetic spectrum (EMS) and how it can be used to describe different land cover;
2. Explore the four basic resolutions of remote sensing imagery and consider how they impact the choice of imagery for specific applications;
3. Learn how to display and conduct basic imagery analysis using GIS software; and
4. Calculate and understand the role of vegetation indices in landscape monitoring.

This chapter is targeted to upper-level undergraduate students with little to no exposure to remote sensing. Some knowledge of GIS and/or Google Earth is helpful for a few exercises. In Exercises 1–3, students will not need a computer and will explore basic remote sensing concepts via pen-and-paper exercises. For Exercise 4, students will need access to a computer with **ArcGIS** (version 9 or higher) to

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explore digital remote sensing imagery and how it can reveal different land cover features. In Advanced Exercise 5 (which also requires **Google Earth**), students will learn how to prepare quantitative representations of vegetation using **NDVI**, a vegetation index often used in landscape monitoring. Synthesis Exercise 6 promotes additional exploration of the remote sensing literature. Prior to starting this lab, students are encouraged to read Chapters 3 and 4 of *Remote Sensing for GIS Managers* by Aronoff (2005). If in-class time is limited, consider completing Exercise 1 prior to arrival in class.

INTRODUCTION

Remote sensing has become an essential tool in many fields such as ecology, geography, geomatics, and resource monitoring as images captured from the air provide important and often unique information on the spatial patterns on the Earth's surface (Colwell 1960). As early as the 1910s, researchers were using remote sensing in forestry to better understand forest extent and condition. The advent of aerial photographic cameras in the 1920s resulted in the development of campaigns by many countries to acquire imagery to survey agricultural lands and to map land cover and land cover change. Satellite-based remote sensing began in the late 1950s and early 1960s, and since then over 100 satellite-based sensors have been launched as part of national and international remote sensing programs.

The sensors used in remote sensing can be categorized as either active or passive. **Passive**, **or optical**, **remote sensing systems** rely on energy and illumination from the sun and utilize sensors which are sensitive to radiation reflected from the 400–2500 nm region of the electromagnetic spectrum. This range includes the visible, near-infrared, shortwave, and mid- and long-infrared regions of the spectrum (Figure 1.1).

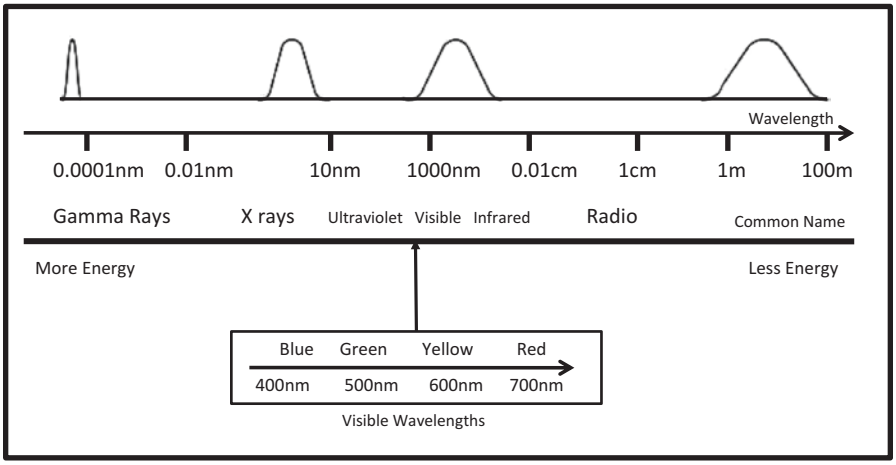

Figure 1.1 Schematic representation of the electromagnetic spectrum (EMS)

Active remote sensing systems are different from passive systems in that energy is emitted from the sensor and either the return time or amount of energy reflected back is measured by the sensor. Having their own power source, such instruments can operate day or night and often under a range of weather conditions. For example, microwave systems can obtain data through cloud cover. The most common active remote sensing sensors are RADAR, which sends and detects microwave wavelengths between 1 mm and 1 m, and **light detection and ranging (LIDAR)**, a more recent technology which most commonly sends and receives near-infrared laser pulses.

Some Remote Sensing Basics

When considering remote sensing imagery for a given application, one must carefully consider image resolutions. These resolutions refer to the four key characteristics of the imagery, including size of individual pixels, overall spatial extent, time interval between acquisitions, and lastly, the region(s) of the electromagnetic spectrum in which the sensor can acquire data and the level of detail (or discrimination) the sensor can provide. Each of these image resolution characteristics is briefly addressed below.

Spatial Resolution

The spatial resolution of a remotely sensed image is the size of the minimum area that can be resolved by the sensor (Strahler et al. 1986) and is generally equated to the pixel size or the "grain" of an image. Depending on the sensor, the spatial resolution can range from submeter to hundreds of meters. For aerial photography, spatial resolution is based on the film speed and the size of the silver halide crystals (Nelson et al. 2001). In the case of digital sensors, an image with a spatial resolution of 30 m resolves a 30×30 m area into a single reflectance response. For satellite sensors, spatial resolution is set at the design phase of the spacecraft, whereas for airborne data, the spatial resolution is governed by the height of the aircraft above the ground.

The spatial resolution provides an indication of what type of detail can be observed on an image. High (or fine) spatial resolution imagery (<5 m) can provide information on small objects such as individual trees, buildings, and cars, whereas low or coarse spatial resolution (>100 m) is more appropriate for observing broad-scale phenomena such as ocean color, broad vegetation phenological responses, and cloud patterns. Historically, medium spatial resolution sensors (10–100 m) (such as **Landsat Thematic Mapper (TM)** and Système Probatoire d'Observation de la Terre (SPOT) multispectral imagery) have provided the optimal resolution for characterizing land cover change and regional disturbance (Franklin and Wulder 2002).

Table 1.1 A sample of spatial resolutions, scene sizes, and potential applications

Spatial resolution	Multispectral sensor	Spectral resolution	Spatial resolution (m)	Spatial extent (km)	Potential applications
Broad	MODIS (MODerate Imaging Spectroradiometer)	405 nm–14.385 μm	250–1000	2330	Ocean color Cloud characteristics
	SPOT (Système Probatoire d'Observation de la Terre) VEGETATION	430–1750 nm	1000	1200	Vegetation productivity Phenology
Moderate	Landsat Thematic Mapper (TM)/ Enhanced Thematic Mapper+ (ETM+)	450–2350 nm	30	185	Land cover Vegetation characteristics Coastal and water
	SPOT	480–1750 nm	5–20	60	
	Indian Resources Satellite (IRS)	520–1700 nm	23–70	142	
Fine	IKONOS	445–853 nm	4	11	Infrastructure mapping
	QuickBird	450–890 nm	2.4	22	Individual tree delineation
	WorldView-2	400–900 nm	1.85	16	Disaster monitoring

The spatial resolution of a sensor is linked to the swath width or instantaneous field of view of the sensor that ultimately determines the spatial extent of the captured image (Lillesand and Kiefer 2000) (Table 1.1). Sensors with a coarse spatial resolution can acquire data over much larger areas, when compared to sensors with very high spatial resolution. As an example, a Landsat TM scene has an image extent of 185 × 185 km (at 30 m spatial resolution), while the MODIS sensor with spatial resolutions of 250 m and larger has an image extent of several thousand kilometers. The spatial extent of data sources must also be considered along with data costs. Coarse spatial resolution data typically cover larger spatial extents and are therefore less expensive per unit area than high spatial resolution data sources. Some medium-resolution imagery (i.e., MODIS, SPOT Vegetation, and Landsat imagery) is freely available, whereas very high spatial resolution satellite systems are often run by private companies resulting in high per unit costs. Increasing spatial resolution presents challenges as image files tend to have large data storage requirements and longer computation processing times. Furthermore, the increased spectral variability within an image with high spatial resolution imagery can confound many commonly used image classification methods such as when individual tree shadows are recorded (Wulder et al. 2004).

Temporal Resolution

The temporal resolution indicates the time required for a sensor to return to the same location on the Earth's surface (i.e., revisit). In the case of satellite systems, temporal resolution is a function of the orbit, image extent, and the capacity of the sensor to tilt and obtain images at requested sites. For Landsat Thematic Mapper imagery, the temporal resolution is 16 days, whereas MODIS with larger extent scene and pixel size has a 1-day revisit. Satellites such as IKONOS and QuickBird use sensors that can point in different directions with short revisit times (varying from 1 to 3.5 days). Such images, however, will be acquired at an angle (known as "off-nadir"). The temporal resolution of airborne sensors is often less critical as image collection via planes is often "on demand" (e.g., coincident with insect outbreaks or fires) (Stone et al. 2001).

Spectral Resolution

Spectral resolution can be considered in three components: the number, width, and location of the spectral wavelength bands detected by the sensor. Some sensors acquire images similar to black and white photography using a single band (or channel) which captures the full range of the visible spectrum (and a small component of the infrared). Known as **panchromatic**, such images are often very useful as they can provide clear and precise spatial information. Detectors with multiple bands (i.e., **multispectral**) have separate spectral bands in the visible (such as blue, green, or red), near-infrared, and mid-infrared regions of the spectrum. As the number of bands increase, **bandwidth** (the range of wavelengths a band detects) often decreases. Sensors with hundreds of narrow spectral bands are known as **hyperspectral**. Currently, most operational remote sensing systems have a small number of broad spectral channels. For example, Landsat Enhanced Thematic Mapper+ (ETM+) has 7 spectral bands in the visible to infrared portions of the spectrum, whereas MODIS has 32 spectral bands. Use of hyperspectral data is increasing because it allows greater discrimination of attributes, such as tree species.

A simplified explanation of spectral resolution for three different sensors is shown in Figure 1.2. The first four bands of Landsat ETM+, SPOT XS, and QuickBird are depicted. Each spectral band covers a slightly different spectral range (or width of band), and the number of bands and the regions of the spectrum detected can vary among sensors.

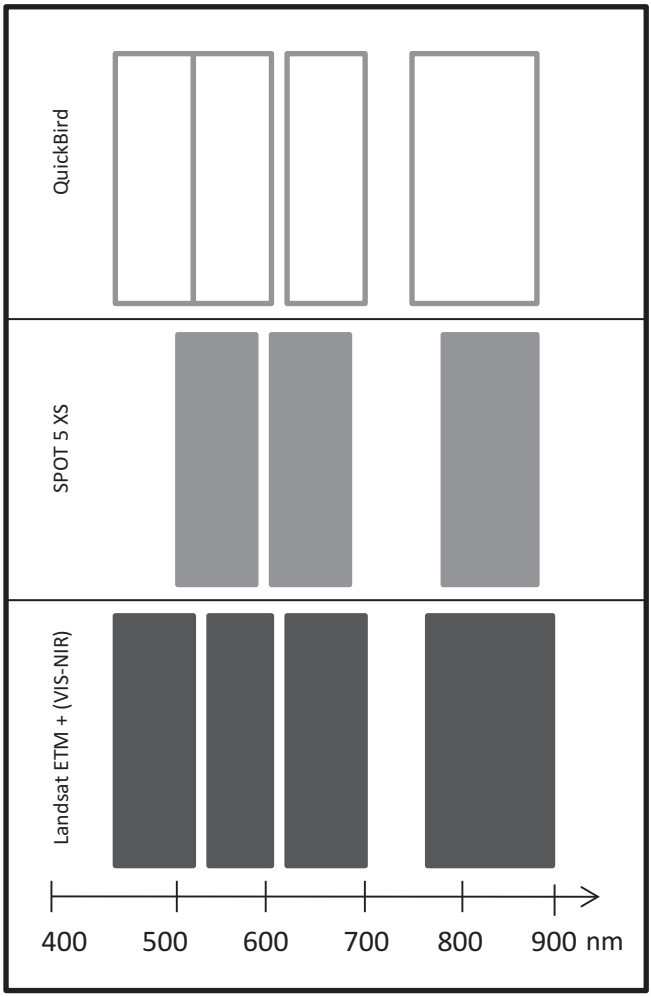

Figure 1.2 The concept of spectral resolution for a subset of bands in three commonly used sensors

Radiometric Resolution

Radiometric resolution provides an indication of the information content of an image. It is often interpreted as the number of intensity (or gray) levels that a sensor uses to quantify the detected reflectance. Generally, the finer the radiometric resolution, the greater sensitivity to detecting small differences in reflectance.

Figure 1.3 provides a simple example of three different radiometric resolutions. In the case of 1 bit, the result would be a binary image of simply pure black and white pixels. 2 bit provides 4 gray levels, whereas 8 bit provides 256 different levels of gray. Most broad- and medium-resolution sensors are 8-bit radiometric resolution. High spatial resolution data such as QuickBird can be up to 11 bit.

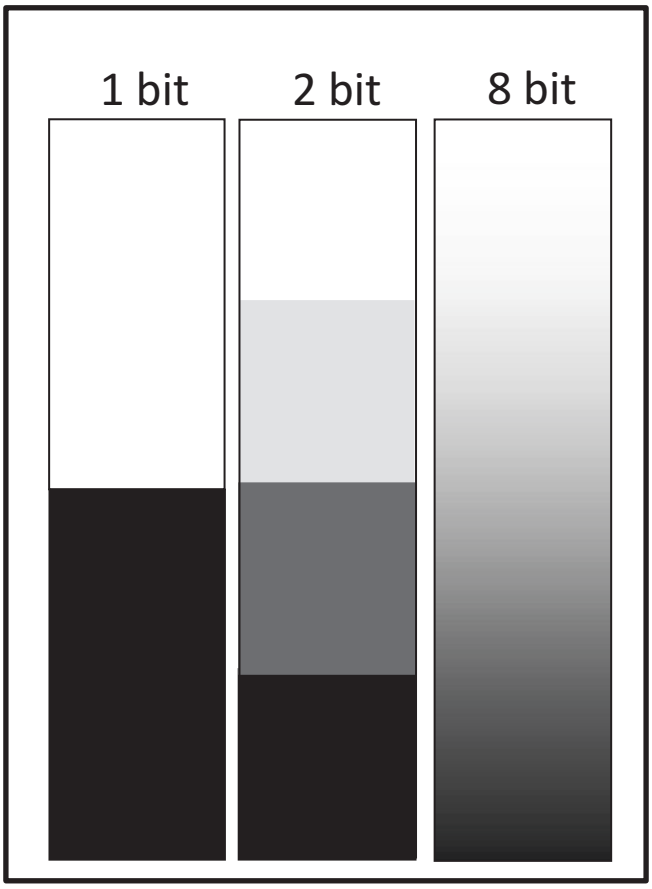

Figure 1.3 The concept of radiometric resolution

EXERCISES

EXERCISE 1: Understanding Spectral Reponses

As discussed earlier, most remote sensing systems measure the amount of reflected radiation from an object within a range of wavelengths of the electromagnetic spectrum. Objects that humans see as bright white, such as clouds or snow, have very high reflectance across all parts of the visible spectrum. For vegetation, leaves reflect more green light than blue or red. Human eyes are unable to see the near-infrared (and many other) regions of the electromagnetic spectrum; however, spectral reflectance curves can be used to show the pattern of reflectance for objects using parts of the spectrum invisible to the naked eye. Figure 1.4 shows a simple spectral curve for six different land cover classes. The *X*-axis ranges from 400 to 1400 nm wavelengths, spanning the visible to the near-infrared region. The *Y*-axis

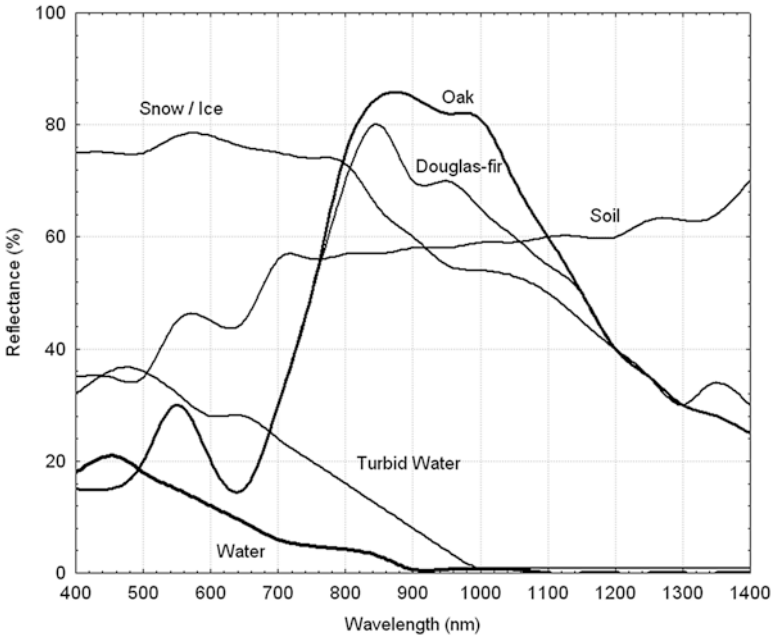

Figure 1.4 Spectral curves for several land cover classes

indicates reflectance where 100% is when all light is reflected in a given wavelength from an object and 0% is total absorption of light by the object.

Q1 What wavelength range has the highest reflectance for snow and ice?

Q2 Identify two wavelength ranges where soil is differentiable from vegetation.

Q3 What is the reflectivity of water at 1200 nm? What are the implications of this for mapping vegetation and water?

Q4 Which wavelengths show the greatest differentiation in reflectance for the two vegetation types?

Q5 The visible part of the spectrum is from 400 to 700 nm. Why is there no separation between the two vegetation types across these wavelengths?

Q6 What wavelength region exhibits the largest change in reflectance for vegetation? Why is this potentially important when looking at different vegetation characteristics?

Q7 What land cover types look almost identical at 700 nm? What about at 1100 nm? What challenges would this pose if you are trying to use these spectral bands to map these land cover types?

Table 1.2 Reflectance characteristics of three unknown cover classes

nm	Class 1 (%)	Class 2 (%)	Class 3 (%)
400	17	10	80
450	18	12	80.5
500	15	18	81
550	12	32	81.5
600	5	21	82
650	0	25	82
700	0	24	82
750	0	40	82
800	0	70	82
850	0	85	82.5
900	0	85	83
950	0	78	82.5
1000	0	75	82
1050	0	65	81.5
1100	0	55	81
1150	0	50	81
1200	0	38	81
1250	0	31	81
1300	0	29	80
1350	0	27.5	80
1400	0	25	80

EXERCISE 2: Detecting the Unknown

Now that you have an understanding of how features and land classes reflect/absorb electromagnetic radiation across the visible and near-infrared regions of the spectrum, in this exercise you will use this background to try and identify some unknown land cover types using only their spectral signatures.

Q8 Use the wavelength and percent reflectance data in Table 1.2 to plot the reflectance curves by hand onto the provided plot on your handout (Figure 1.4).

Q9 Based on the known reflective properties of various classes and what you have learned about spectral signatures, which classes refer to cedar forest, deep water, and cloud? Explain how you determined this.

EXERCISE 3: What Can Be Seen from Space?

Most satellite systems have a limited number of spectral bands with which to detect a spectral signature. In the following exercise, you will draw the location and width of the spectral bands of a number of satellite sensors and estimate what each land cover types looks like when viewed by different sensors types.

- Using Table 1.3 and several printed copies of the vegetation spectral curve handout as shown in (Figure 1.5), draw boxes that represent the spectral channels of the Landsat ETM+, Spot 5 XS, and QuickBird satellite sensors.
- Complete a new graph for each sensor and work in teams if appropriate. *NOTE*: The spectral range (*X*-axis) of this figure differs from Figure 1.2.

Q10 For each sensor, draw each spectral channel as a box (similar to Figure 1.2) using a separate copy of Figure 1.5 for each.

Q11 Once you have drawn the boxes for each sensor, draw a line across each box to approximately represent the average spectral response of vegetation within each spectral channel.

Q12 For each sensor, connect the average spectral responses for each box/channel to draw the plot of the vegetation spectral signature as seen by each sensor.

Q13 How does the averaged spectral curve differ between sensors? Which sensor reproduces the vegetation spectral curve the best? Which is more important, the number of bands or where they occur across the spectrum?

EXERCISE 4: Visual Representations of Satellite Imagery

Now that you have completed some manual interpretation of spectral signatures, we will move on to exploring actual satellite imagery using computer software. In the following exercise, you will use ArcMap, a powerful GIS analysis program for use with both vector and raster file formats. While sample Landsat satellite images for select locations have been supplied for this exercise, the entire Landsat archive covering the entire Earth is available for free and can be accessed using the United States Geological Survey's Global Visualization Viewer (http://glovis.usgs.gov). Here, you will examine a Landsat scene covering the city of Vancouver in British Columbia, Canada.

In this section, you will explore basic computer visualization techniques, allowing you to produce various color representations of a single satellite image. Computer displays typically use a combination of red, green, and blue colors to display images on the screen. Each of these colors is assigned a **color channel**, and the different combinations of values for each channel are used to produce a range of colors. When viewing satellite imagery, we assign a different satellite band to each of the color channels. Since many sensors collect more than three bands of spectral information, as we learned earlier, there is a wide range of color combinations that can be displayed. The first combination of satellite bands to display will visualize the imagery as it normally appears to the human eye. This is what is referred to as a **true color composite**.

1. Double-click **Exercise4.mxd** to start ArcMap with the Vancouver Landsat imagery.

Table 1.3 Spectral ranges of selected satellite sensors

Sensor	Wavelength range (nm)
Landsat ETM+	
Blue	450–510
Green	520–605
Red	630–690
Near infrared	750–900
Shortwave infrared	1550–1750
Thermal	10,400–12,500
Shortwave infrared	2080–2350
SPOT 5 XS	
Green	500–590
Red	610–680
Near infrared	790–890
Shortwave infrared	1580–1750
QuickBird	
Blue	450–520
Green	520–600
Red	630–690
Near infrared	760–900

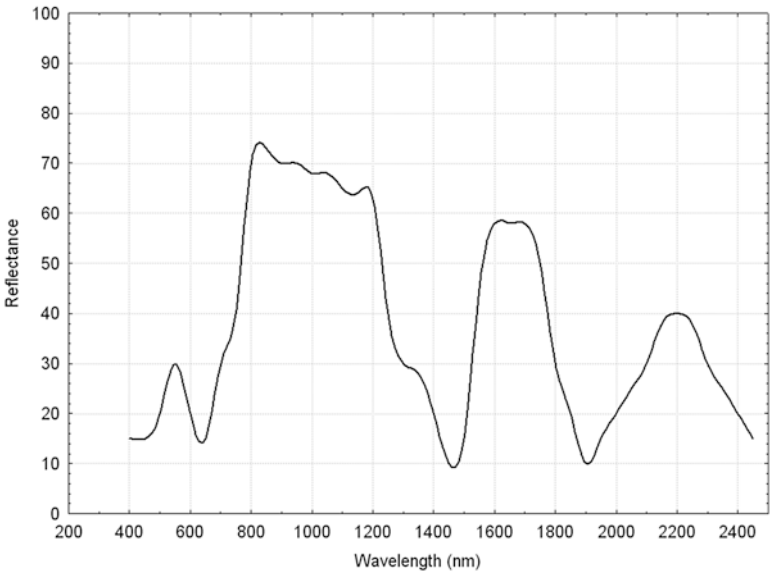

Figure 1.5 Typical vegetation spectrum

2. Right-click the **LandsatYVR** raster, choose **Properties**, and then select the **Symbology** tab from the top menu.

Notice the bands and pull-down menus associated with each color channel. Bands 1, 2, and 3 of the Landsat imagery correspond with the blue, green, and red region of the spectrum, respectively.

3. Now click on the **Histograms** button and notice the statistics for each of the color channels.

Q14 What is the range of values for each color channel?

In this imagery, there are 256 values (0–255) that can be stored for each band. Recall the earlier description of radiometric resolution, in terms of bits, which are the basic unit of information in computing and can only be one of two values (0 or 1). Notice that $2^8 = 256$; therefore this imagery has an 8-bit radiometric resolution.

Satellite imagery captured across different regions of the EMS allows us to examine information not visible to the human eye. Interestingly, many organisms perceive different regions of the EMS than humans can detect (e.g., ultraviolet light is visible to some birds and bees). Humans can, however, create alternative views of a landscape that highlight various features using different combinations of satellite bands with different color channels, creating a **false color composite**. There is a wide range of false color composites that can be created from combining different satellite bands.

4. Select one of the three unique regions (Dubai, Haiti, oil sands) and open the associated **.mxd** file. Explore different, unique combination of bands that highlight different feature attributes.

Q15 Create two separate representations of your chosen scene. Try to create contrasting representations which highlight different features. Create your new representations by associating different bands with different color channels. List some of the observable features in each of your two new images.

5. Lastly, test your feature identifications using higher spatial resolution imagery. Open the program **Google Earth** from the start menu, and direct the viewer to the same location as your Landsat image. Use the provided ***.xml** files, if needed, which are compatible with Google Earth.

Q16 How accurate were your observations? Did anything in particular surprise you? Find someone in the class exploring a different location. Discuss some of the similarities and differences between your regions, the features visible in your satellite-image color composites, and how they compare with higher spatial resolution imagery.

ADVANCED EXERCISE 5: Using Satellite Indices - the Normalized Difference Vegetation Index (NDVI)

To represent specific attributes, remote sensing scientists often compute the difference between image bands to produce a new layer. The resulting layer is referred to as an index, due to its ability to facilitate the extraction of specific information related to ground features. A common index in remote sensing is the **Normalized Difference Vegetation Index (NDVI)**. This index utilizes the difference between the near-infrared region of the spectrum (where vegetation displays high reflectance) and the red region (where vegetation has a very low reflectance). The utility of NDVI comes from its ability not only in identifying vegetation classes but also in differentiating vegetation species and assessing the condition and health of vegetation. NDVI has been used extensively for a wide range of ecological mapping applications, in harvesting operations, as well as in conservation planning and vegetation assessment.

Calculating NDVI

In this exercise, you will learn how to create an NDVI image using Landsat satellite imagery and understand how it can be used as an index of vegetation condition. You will see how different land cover types produce different NDVI values. Vegetated areas generally have higher NDVI values, making the development of a vegetation mask (or layer) a relatively routine and easy task.

1. Double-click **AdvancedExercise.mxd** to start ArcMap with the same Vancouver Landsat imagery used in the previous exercise.

Notice that each of the bands from the Vancouver Landsat scene is now loaded independently. Each band represents a region of the electromagnetic spectrum as indicated in Table 1.3 starting with band 1 as blue.

2. Compare the differences in the radiance between bands by turning each of the bands on and off by clicking the check box beside each layer.

Q17 From your knowledge of spectral signatures, which two of the Landsat satellite band numbers correspond with the highest and lowest reflectance for vegetation?

3. From the top menu, choose **Geoprocessing** and select **Search For Tools**.
4. In the search space, type **Raster Calculator** and then hit **Enter** and select the **Raster Calculator (Spatial Analyst)** tool from the top of the search list.

NOTE: The Spatial Analyst extension must be enabled before using the Raster Calculator tool. You can turn on the extension (if available with your license) by choosing **Customize** from the top menu, selecting **Extensions**, and ensuring that the **Spatial Analyst** box is checked.

5. In the map algebra expression space, enter the following:
   `Float("LandsatYVR.tif-Band_4" - "LandsatYVR.tif-Band_3")/Float("LandsatYVR.tif-Band_4" + "LandsatYVR.tif-Band_3")`
   - Then give the *Output raster* a location and name you will remember (and where you have permissions!) and click **OK**.
   - The new layer should display a grayscale image of NDVI values
6. Use the identify tool to examine NDVI values for individual pixels in your NDVI layer.

Q18 Clearly some features have higher NDVI values than others. Using a combination of the color composite image and the NDVI layer, what cover types look to be at the extreme ends of the range of NDVI values?

Q19 Provide some ideas as to why different vegetative cover types display different NDVI values

Q20 Return to Google Earth and check your work from *Q18*. Are there any cover types or features that presented NDVI values that seem surprising or incongruous? Why might that be?

Q21 What are some ways that you might use NDVI to map vegetation cover? What other data are needed to accomplish this?

Image Thresholding

In the next few steps, you will learn to use the NDVI layer to classify vegetation using a **thresholding technique**. A threshold is a limit used to divide a continuous set of values. Thresholding is a common approach used in remote sensing to classify one or more land cover features from an image. Thresholding can be done both manually with user-determined threshold values or automatically using statistical methods.

7. Using the identify tool to explore the NDVI layer you created in the previous step. Find the lowest value that you consider to be vegetation. Feel free to use Google Earth as a reference.
8. Open the Raster Calculator tool again, and in the map algebra expression space, enter
   `raster_NDVI>x`
   where *raster_NDVI* is the name of the NDVI layer you created in the previous step and *x* is your determined threshold value. Click **OK**.

The resulting layer is a binary image which contains two values. A value of 1 indicates that a condition has been met, and 0 indicates where a condition has not been met.

Q22 In the binary image that you created, what do the values 1 and 0 represent?

Q23 What benefits does a binary image like this offer for analysis? What are the disadvantages?

Exporting Your Images

The last step is to export your binary image so you can use it at a later date or with different software packages. One of the most common storage file formats for spatial raster datasets is a GeoTIFF, which you will use here to store your classified vegetation layer.

9. Right-click the most recent layer representing the vegetation extraction in the **Table of Contents pane**, choose **Data**, and select **Export Data**.
10. From the **Format** drop-down menu, select **TIFF**.
11. Choose a location folder and enter a name for your export layer (ensuring that it ends with the extension *.tif*) and then click **Save**.

Q24 Do a quick web/article search and list several of the various satellite-image-based indices that have been used to identify land cover features or phenomena. Select an index from your list and apply it to one of the three other locations (Dubai, Haiti, oil sands). Discuss how the index you selected might be useful for informing land use management at your location.

SYNTHESIS EXERCISE 6: Remote Sensing Applications

From your understanding of this brief introduction to remote sensing and vegetation analysis, find a research article that interests you and is pertinent to your studies which utilizes remote sensing. Read and prepare a brief review. The purpose of doing this is to familiarize yourself with remote sensing literature and relate the remote sensing concepts above to your specific interests.

You may choose any paper on remote sensing of vegetation; however, the paper should be no more than 5 years old. The best way to conduct this search and find a paper is online or by browsing through the remote sensing journals available in university libraries. In addition, there are several remote sensing journals, all of which contain papers that would be quite suitable for this exercise. In your search, consider searching for the term NDVI.

Your summary should be about two pages long and include the following:

- Describe why this paper is of interest to you.
- How did you find the paper?
- What type of remote sensing imagery has been used?
- Was the NDVI, or a similar vegetation index, calculated?

- How was it used in the study?
- Location/region of the study.
- What are the general outcomes/results?
- What were some of the sources of error in the study? Were they discussed?
- A paragraph indicating if you would have undertaken the study any differently.

Be prepared to also hand in a copy of your chosen journal article when you hand in your write-up.

CONCLUSIONS

Remote sensing is a dynamic and rapidly evolving field. You are encouraged to explore the recommended readings for additional ideas and applications for remote sensing. In addition, a subsequent chapter in this book (see Chapter 11 Using Spatial Statistics and Landscape Metrics to Compare Disturbance Mosaics explores the use of other vegetation indices for mapping disturbances such as fire and insect outbreaks. This advanced chapter also explores the implications of using thresholding techniques versus binary maps to represent and analyze landscape disturbance, building on the foundations of remote sensing you examined here.

REFERENCES AND RECOMMENDED READINGS[1]

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