An Introduction to Satellite Imagery Analysis for Land Managers

A step-by-step guide to downloading, interpreting, and classifying satellite imagery using free software

Image Credit: USGS/NASA Landsat

extension
ALABAMA A&M & AUBURN UNIVERSITIES

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Part 1. Introduction

Satellite imagery analysis and other remote sensing techniques have become an integral component of land and natural resource management, particularly among government agencies, NGOs, and private companies that can afford to hire remote sensing specialists. Smaller organizations, however, may lack the resources to staff a dedicated remote-sensing or GIS (geographic information system) position. Fortunately there are free tools available that allow nonspecialists to access and analyze satellite imagery to help achieve natural resource management objectives.

This guide provides a brief introduction to the applications and basic concepts of satellite imagery analysis. This is followed by step-by-step instructions* on how to access and analyze up-to-date imagery. The instructions are based on a case study involving detection and mapping of the invasive shrub Chinese privet (*Ligustrum sinense*) in a bottomland hardwood forest.

Land Management Applications

Broad applications exist for satellite imagery analysis in land and natural resource management. Most of these fall under the umbrella of land cover analysis. Knowing the proportion and location of different land cover types on a property is useful when developing management plans and monitoring the results of actions.

Land cover types that land managers may be particularly interested in mapping include forests, wetlands, invasive plant species, and agriculture. Satellite imagery also can help managers monitor plant health over large areas, such as detecting insect damage or drought stress.

Novel uses for satellite imagery and other remote sensing products are continuously being developed. As more land managers, foresters, and biologists begin using these tools, their fresh perspectives are likely to help drive innovation.

Basic Concepts

Humans see the world based on light reflecting off objects in the visible range of the electromagnetic spectrum (i.e., red, green, blue). Most consumer-grade cameras, such as those found in smartphones, capture light within or near this range to produce images that are similar to what we see with the naked eye.

Satellite sensors used for land cover analysis sample light reflecting off Earth's surface in wavelengths outside the visible range. These multispectral sensors capture more information about the surface of the planet than could be gathered using a regular red-green-blue (RGB) camera. Sampling in the infrared portion of the spectrum is particularly useful for mapping vegetation because leaves tend to strongly reflect near-infrared radiation.

Multispectral satellite sensors sample discrete bands within the electromagnetic spectrum. The number of bands sampled determines the spectral resolution. The data gathered by the multispectral sensor can be

*Step-by-step instructions for software in this guide are based on the Windows operating system. This workflow is also possible on MacOS X, Android, and Linux systems but may require slight modifications.

used to construct spectral signatures for land cover types.

Spectral signatures are representations of how different land cover types reflect light with varying intensity across the electromagnetic spectrum (figure 1). These differences in reflectivity arise due to differences in pigmentation, water content, texture, and other factors. Satellites with higher spectral resolution (i.e., more bands) can produce more detailed spectral signatures, which is helpful for differentiating between land cover types with similar spectral characteristics.

Remote sensing software can be used to create land cover maps from satellite images in which each pixel in the image is classified into a specific land cover category. To create a land cover map using supervised classification, the user starts by creating training sites. This is done by manually labeling the land cover in a small portion of the satellite image. The software then calculates the spectral signature of each land cover type based on the training sites. Next, it calculates a spectral signature for each pixel in the image, compares that signature to the signatures derived from the training areas, and sorts the pixel into the land cover class that is the closest fit. This process is covered in greater detail in Part 4 of this publication.

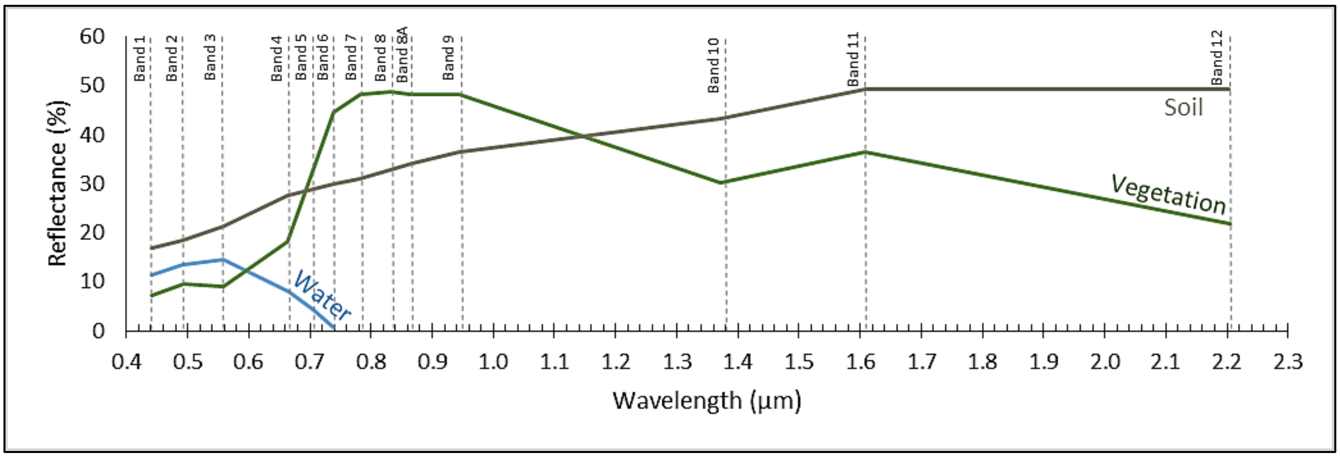


Figure 1. Example spectral signatures for bare soil, vegetation, and water. This example is based on center wavelengths of Sentinel 2 spectral bands. Modified from seos-project.eu, based on Siegmund and Menz (2005).

Part 2. Sentinel and Landsat Imagery

Background and Specifications

Multispectral satellite imagery is freely available through several sources. The United States' Landsat series and the European Space Agency's (ESA) Sentinel 2 constellation are perhaps the most commonly used.

The first Landsat satellite was launched in 1972. Now in its eighth generation, the Landsat program provides an unparalleled data archive that is crucial for land cover change analysis. The current generation (Landsat 8) has 11 bands with spatial resolutions of 15, 30, and 100 meters (m) (table 1). Spatial resolution refers to the dimensions of the area on the ground that each pixel in the image represents (e.g., a 30 m resolution means that each pixel is 30 × 30 m).

The temporal resolution of Landsat 8 is 16 days at the equator, meaning that new images are acquired roughly every 16 days for any given location. Areas near the poles are imaged more frequently due to the polar orbit of the satellite. The Landsat 7 is still in operation, giving a combined 8-day temporal resolution for the pair. A sensor failure on Landsat 7, however, creates lines in the imagery that can complicate interpretation and classification; therefore, Landsat 8 is more frequently used.

Table 1. Landsat 8 Spectral Bands (Source: USGS)

Band	Spatial resolution (m)
Band 1 - Coastal aerosol	30
Band 2 - Blue	30
Band 3 - Green	30
Band 4 - Red	30
Band 5 - Near Infrared	30
Band 6 - Shortwave Infrared 1	30
Band 7 - Shortwave Infrared 2	30
Band 8 - Panchromatic	15
Band 9 - Cirrus	30
Band 10 - Thermal Infrared 1	100
Band 11 - Thermal Infrared 2	100

Sentinel 2 is a pair of satellites that launched in 2015 and 2017. Together they have a 5-day temporal resolution. Both satellites have 13 bands with three spatial resolutions: 10, 20, and 60 m (table 2).

The greater spatial, spectral, and temporal resolution of Sentinel 2 tends to give it an advantage over the Landsat system for many, but not all, land cover applications. Higher spatial resolution allows finer grain details to be discerned in the imagery. This may or may not be important depending on the scale of the mapping project.

Greater temporal resolution increases the chances of acquiring cloud-free imagery within short windows of time, something that can be difficult in regions with long rainy seasons. This can be important when trying to find imagery from a specific time period or when relying on near real-time updates for deforestation or flood monitoring. The greater temporal resolution also provides

Table 2. Sentinel 2 Spectral Bands (Sources: Congedo, 2016, and ESA, 2015)

Band	Spatial resolution (m)
Band 1 - Coastal aerosol	60
Band 2 - Blue	10
Band 3 - Green	10
Band 4 - Red	10
Band 5 - Vegetation Red Edge	20
Band 6 - Vegetation Red Edge	20
Band 7 - Vegetation Red Edge	20
Band 8 - Near-infrared	10
Band 8A - Vegetation Red Edge	20
Band 9 - Water Vapor	60
Band 10 - Shortwave Infrared (Cirrus)	60
Band 11 - Shortwave Infrared	20
Band 12 - Shortwave Infrared	20

more data for time series analyses. As covered previously, greater spectral resolution increases the ability to distinguish among spectrally similar land cover types.

Although Sentinel 2 has many benefits, Landsat provides the crucial ability to compare new imagery to a decades-long archive. In addition, the coarser spatial resolution can actually be beneficial when working over very large areas due to the smaller file size.

Visual Interpretation

Although software can utilize the full set of bands from a multispectral sensor to calculate spectral signatures, humans are still limited to seeing combinations of red, green, and blue. To visualize the spectral bands from outside the visible range, we can assign those bands to one of the three primary colors (red, green, blue), hence creating a false color composite.

False color composites are typically designated using three numbers separated by hyphens; the first number represents the satellite band assigned to red, the second number to green, and the last number to blue. For Sentinel 2, a color combination of 4-3-2 is a natural color image, whereas 8-4-3 is an infrared false color composite (table 2) that highlights living, nondormant vegetation in red/pink (figure 2). Other combinations are useful for emphasizing different land cover features, and it is typically a good idea to experiment with different band combinations to identify the best option for a given application.

It is often useful to take vegetation phenology into consideration to help distinguish between similar vegetation types. For instance, deciduous and evergreen trees may have similar spectral signatures and be hard to distinguish during the growing season. During the dormant season, however, when the deciduous trees have dropped their leaves, there is much greater contrast. In our classification case study in Part 4 we show how phenological differences can be used to detect invasive evergreen shrubs in deciduous forests. Targeting specific time periods can also be used to distinguish among crops with different planting and harvesting schedules.

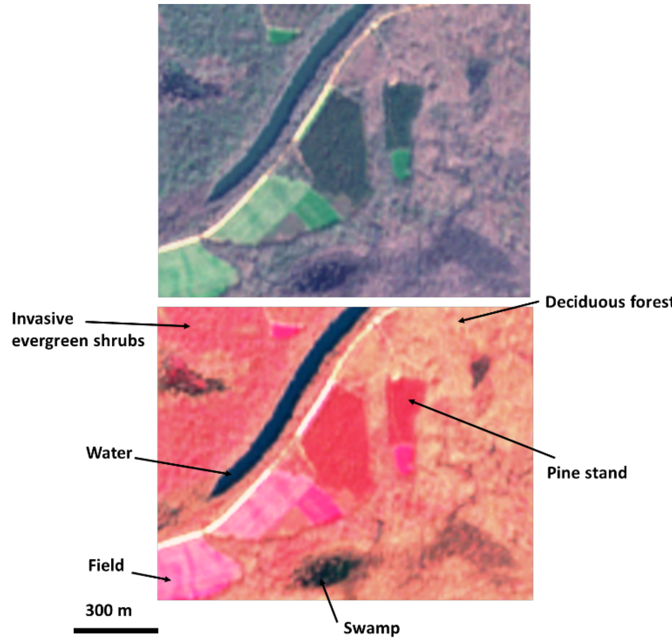


Figure 2. Comparison of natural color (top) vs. false color infrared (bottom) dormant season Sentinel 2 imagery of a bottomland hardwood forest in Alabama. The false color infrared is particularly useful for distinguishing between deciduous forests invaded by privet—an evergreen shrub—and uninvaded forests. This is an L1C image with DOS1 atmospheric correction and gain increased to 4.0 to maximize visual contrast. Modified Copernicus Sentinel data 2017/Sentinel Hub

Viewing Online

Sentinel 2 and Landsat 8 imagery can be viewed for free online using EO Browser at https://apps.sentinel-hub.com/eo-browser/. EO Browser can be used to access up-to-date and archived Sentinel 2 and Landsat 8 images as well as several other satellites. Images are searchable by date and cloud cover. Using EO Browser allows quick and easy viewing of up-to-date or archived imagery without needing to download large files.

The first time you use EO Browser, a pop-up should appear to provide a quick tutorial on the basic features of the web page. You can click the  button in the top right corner to view the tutorial again.

To view imagery, start by zooming to your area of interest on the base map. Choose the data source, date range, and max cloud cover using the **Search** tab. Note there are two options for Sentinel 2 imagery, *L1C* and *L2A*. These designations refer to the level of preprocessing that the images received. L2A images have been corrected by the ESA for atmospheric interference, such as haze, and tend to have greater color contrast. L2A images are not always available, however, due to data gaps; therefore, L1C sometimes must be used. Less sophisticated atmospheric corrections can still be applied to L1C images if necessary.

Images are viewed by clicking on **Visualize** under the **Results** tab. In the visualization tab you can choose one of several pre-set band combinations to view the imagery. The **Custom** option allows you to create any band combination you choose. The  button provides additional visualization options. The **Atmospheric Correction** drop-down menu allows you to apply a DOS1 or statistical correction to Sentinel 2 L1C images, if desired. The **Gain** and **Gamma** sliders can be used to increase contrast in the image, which can be useful for distinguishing between spectrally similar land cover types. Use the  tool to return to the band combination page.

Downloading Imagery

For some applications, informal visual interpretation of multispectral imagery using EO Browser or other online option may be sufficient for natural resource–related planning or monitoring. For situations where a classified land cover image is necessary, EO Browser can be used to scout for images that are of appropriate quality to download and analyze further.

EO Browser has the capability to export imagery; however, the exported images tend to have inconsistent spatial resolutions. Consistency in spatial resolution is particularly important when using land cover maps to track change over time, as is often the goal. It may be better, therefore, to download imagery from either the US Geological Survey (USGS) or the ESA. The USGS website https://earthexplorer.usgs.gov provides data archives for Landsat 8 and Sentinel 2 along with a variety of other data sources. A free account is required, which can be created using the **Register** tab at the top right of the web page.

To find appropriate imagery, begin by zooming in on your area of interest using the Google base map. Click on the map to draw a rectangle around your desired site (each click sets a corner pin for your area of interest). If you used EO Browser to find a specific image, you can add that image date to the mm/dd/yyyy fields under the **Date Range** tab. If you still need to identify an appropriate image, input a range of dates that are likely to provide reasonable imagery. Too narrow a range limits the chances that good cloud-free imagery will be available, while too wide a range may bring up old imagery that isn't representative of current ground conditions. Therefore, keep project objectives and local land cover dynamics in mind when choosing dates. Specific months within the date range also can be selected using the **Search Months** drop-down menu. This is useful when trying to target a specific part of the vegetation growth cycle.

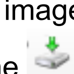
Once you've chosen your dates and area of interest, the next step is to choose the image source you want to use. Click on the **Data Sets** button. Click the + button next to each data set name to open up further options. Check the box next to the image source you want. Multiple Landsat options are available for use.

Level 1 data have basic preprocessing steps completed but are not atmospherically corrected. This may or may not be important depending on the needs of the project. Atmospheric correction reduces haze and helps to standardize radiance values, which is important when using a single trained classifier on multiple images.

Analysis Ready Data (ARD) are atmospherically corrected and are usually the best option, but may not be available for all dates. If ARD products are not available for a specific date, Level 1 products should be adequate. Sentinel 2 images are only available as L1C products from USGS. If L2A atmospherically corrected products are needed, they can be downloaded from https://scihub.copernicus.eu/dhus/#/home. See Song et al. (2001) for more information on when atmospheric correction is necessary.

Once you've selected your data source, click on **Additional Criteria**. The most useful feature on this page is the **Cloud Cover** filter, which allows you to filter out images with a cloud cover greater than a specified level. Keep in mind that the cloud cover percent is for the entire image (also known as a *scene*), which is over 100 kilometers (km) wide for both Sentinel 2 and Landsat 8. This means that if your area of interest is small, it may be possible to get a cloud-free image of the site even if the entire scene has high cloud cover. Don't be too aggressive with the cut-off filter you set because you may exclude usable images from your search results.

Now click on the **Results** button and scroll through the images to decide which to download. A coarse resolution preview image can be displayed by clicking the  button for each image. Click the same button to remove the preview so that new images can be viewed. You may notice that some images have a significant amount of black space. This is a by-product of the images being reprocessed into a different tiling system. Look for images in which your area of interest isn't covered by clouds, cloud shadows, or one of the no data black spaces.

Once you've found an image that meets your needs, click on the  button to view download options. For Sentinel 2 images you want to choose the *L1C tile in JPEG2000* option. For Landsat you need the *Level 1 GeoTIFF data product* or *surface reflectance* if using the ARD dataset. Your image will download as a compressed .gz, .tar, or .zip file (based on the data type) and may take a few minutes depending on your internet connection. Depending on the size and location of your study area you may need to download multiple images.

Once the file is downloaded, move it out of your **Downloads** folder and into a dedicated project folder of your choice under **Documents** (in your computer's **File Explorer**).The .gz, .tar, or .zip file is a compressed file that will need to be extracted using software such as 7-Zip (available at https://www.7-zip.org/download.html). Download the 7-Zip .exe file that matches your system requirements (32 bit or 64 bit). Most modern PCs are 64 bit, but you can check your computer by opening the settings and clicking on **System** then **About**. Whether you have a 64 bit or 32 bit device will be listed under **System Type**. Once you've downloaded the correct .exe file, open it and follow the prompts to install the 7-Zip program.

Once 7-Zip is installed on your PC, navigate to the compressed file and right click on it. Choose **7-Zip** then **Extract Here**. For Sentinel 2 and Landsat ARD products, the files should now be fully extracted and ready for processing. For Landsat Level 1 products, the .gz file will extract a .tar file, and the previous step will need to be repeated (two layers of compression are used due to the larger file size).

Part 3. QGIS: Free Open-Source Mapping Software

QGIS is open source (free) mapping software that can be used to organize, create, and display geospatial data. This section covers some basic functions in QGIS, including adding, creating, and modifying data layers. This will barely scratch the surface of what QGIS is capable of. We suggest users consult the QGIS documentation available at https://qgis.org/en/docs/index.html for information on additional functions or clarification on the topics covered in this section. There also is a strong online user community that can answer questions and help you work through errors or other problems. Find them at https://gis.stackexchange.com/questions/tagged/qgis.

Download and Setup

QGIS can be downloaded at https://qgis.org/en/site/forusers/download.html. Two options are available: the latest release and the long-term release repository. The latest release will have the most up-to-date features while the long-term release will be more stable. In our experience either version should work fine.

Once you've decided on a version, choose the **QGIS Standalone Installer Version [version number]** appropriate for your operating system. Click on the .exe file when it is finished downloading and follow the prompts to complete the installation. The instructions in this guide are based on version 3.4, but the steps likely will be similar for future versions.

Once QGIS is installed, launch the software by clicking on the Windows button and searching for it in your app list. Open the QGIS folder and double-click on **QGIS Desktop [version number]**.

Once QGIS is open, click the **Plugins** tab on the top banner and choose **Manage and Install Plugins**. Use the search bar to find and install the Semi-Automatic Classification Plugin (SCP).

Adding Data

Two main types of data can be loaded into QGIS for viewing, editing, and analyzing: *raster* and *vector*. Satellite imagery is a type of raster data. Raster files are grids of pixels (cells) in which each pixel contains a single value. In the case of optical satellite imagery (e.g., Sentinel 2 and Landsat), the pixel values represent the amount of solar radiation within a spectral band being reflected off the surface of the earth within the area sampled by each pixel (plus potential atmospheric interference). Common raster data formats include .tif and .jp2.

Vector files are made up of points, lines, or polygons. A vector layer may contain many features (i.e., separate points in a point-based vector layer). Information about each feature in a vector layer is stored in an attribute table, which contains one row per feature and as many columns of attribute information as needed. Vector files are useful for delineating property boundaries, roads, and infrastructure.

Vector layers typically are composed of three separate files with .shp, .shx, and .dbf extensions, and they also may include .xml, .prj, .sbn, and .sbx. All supporting files for a layer need to be in the same folder, but when adding the layer to QGIS you only add the .shp file. Raster files often include an .xml supporting file, but again you only need to add the actual image file (.tif, .jp2, etc.) to QGIS.

Data are added to QGIS using the button, which is located on the far left of the third row of the top banner (figure 3). Clicking on the button opens a pop-up (data source manager) with a list of data types along the left side. Choose **Vector** or **Raster** depending on the file you plan on adding. Under **Source** click on the ... button to the right of the page. This will open up your file explorer. Navigate to your file, click on it, and select **Open**. Click **Add** at the bottom of your data source manager pop-up.

To add your downloaded Landsat imagery to QGIS, open the **Data Source Manager** and click **Raster**, then open your file explorer using the ... button. Navigate to the folder where the imagery is stored. Each image band (red, green, blue, near-infrared, etc.) is stored as a separate image file.

There are also additional image files with information on cloud cover and other image-quality information. The last two digits in the file name identify what band the image represents. You can add multiple bands at once by holding the **Ctrl** button on your keyboard and clicking on each image file. Click **Open** then **Add**.

Sentinel 2 data are a little harder to find in your file folder. Begin by opening the main folder containing the imagery and click on **Granule**. This should contain a single folder. Open it and click on IMG_DATA to find the image files (stored as .jp2 files). Part 4 of this guide will cover the image bands that are most important for land cover classification and demonstrate how to combine these bands into a band set.

Each of the images that have been added to QGIS will appear under the **Layers** list on the left side of the interface. Click the box next to a layer to toggle it on or off. You can change the order of the layers in the list by clicking and dragging them. The order of the layers in this list determines the order they are rendered on the screen. Small layers should be ordered higher than larger layers (such as base maps) or they will be obscured. Layers can be removed by right clicking on the layer and choosing **Remove Layer**, which will remove the layer from QGIS but not delete it from your computer.

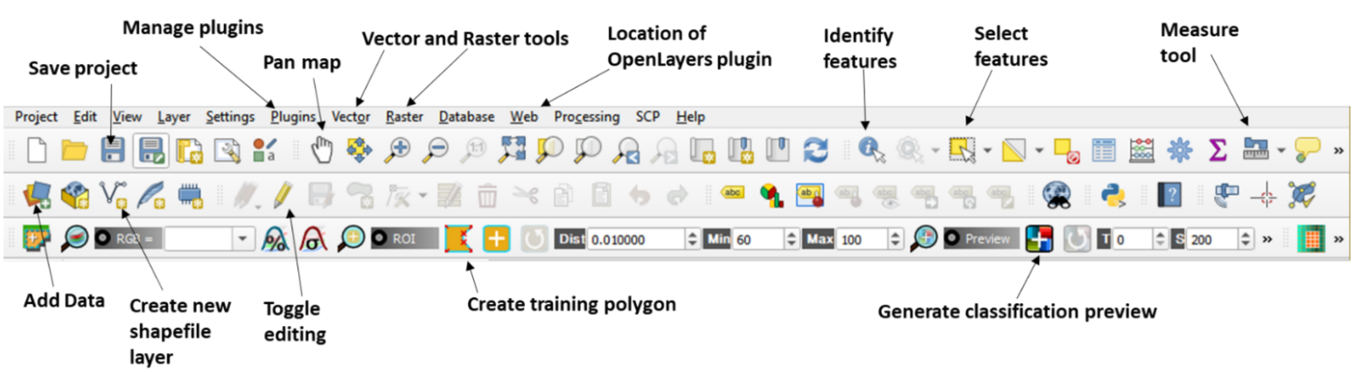


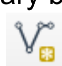
Figure 3. Top banner of QGIS interface, with important tabs/buttons identified. Note that the entire bottom row is devoted to the Semi-Automatic Classification Plugin.

Creating and Editing Vector Layers

A vector layer of a property boundary is useful for satellite imagery analysis because you can clip the imagery to your specific area of interest to eliminate unnecessary processing and allow for easy calculation of the acreage of different land cover types.

Property boundary layers for state and federal public lands are typically available either online or can be requested from the relevant agency. Private property boundaries may be more difficult to acquire.

Sometimes the local tax assessor office has vector files that can be accessed online or through a direct request, but this is not always the case. If you cannot find a pre-made property boundary vector file, there are a few options for creating your own.

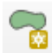
One option is to trace the boundary by hand in QGIS. Start by clicking on the  button (third row from the top) to pull up a dialogue box to create your new shape file. For your file name, click on the  button to the right of the box to open up your file explorer. Navigate to your project folder then create an appropriate file name in the file name text box and click **Save**. Note that it is good practice to avoid spaces in file names; instead use ‘_’ or ‘-’ to separate words. Under **Geometry Type**, use the drop-down menu to select **Polygon**. The next drop-down menu contains an EPSG number, which likely will be 4326-WGS 84 by default. This is your coordinate reference system (see note below for more details). Click **OK** to finish creating the layer. The new layer should now appear in your layers list, but there will not be anything new on the map.

Next, you can add a base map that will serve as a reference when you are tracing the outline of the new vector layer by hand. You could use Landsat or Sentinel 2 imagery as a base map, although they may not have high enough resolution to see details that mark property boundaries. In the United States, the National Agriculture Imagery Program (NAIP) is a good option

Coordinate reference systems: Displaying the surface of the curved earth on a flat screen or piece of paper is difficult, as there always will be trade-offs between minimizing distortions in surface area, shapes, and/or angles. Even displaying the surface of the earth on a digital sphere or ellipsoid is difficult because the earth isn’t perfectly round or smooth. A geographic coordinate system is a digital model of the ellipsoidal surface of the earth, while a projected coordinate system is a transformation of an ellipsoid onto a flat surface. Your choice of coordinate reference system depends on your location (some are location-specific, others are global) and will affect the physical appearance of your map as well as measures of area, length, and angles. Using layers with different coordinate reference systems may lead to location error in your maps, although the on-the-fly projection feature of QGIS typically limits such problems. We recommend consulting the following web pages for more information on choosing an appropriate coordinate reference system and managing your coordinate reference system in QGIS:

https://docs.qgis.org/3.4/en/docs/gentle_gis_introduction/coordinate_reference_systems.html

https://docs.qgis.org/3.4/en/docs/user_manual/working_with_projections/working_with_projections.html for high resolution aerial imagery. It can be downloaded from the USGS Earth Explorer website and added to QGIS using the same steps detailed above for Landsat/Sentinel 2 imagery. When searching for NAIP imagery under the **Data Sets** tab in Earth Explorer, choose **Aerial Imagery** and then **NAIP**. The imagery will be downloaded as a .zip file that will need to be unzipped in order to add the TIF image file to QGIS.

To draw the property boundary, select your new layer in the layers list (it will now be underlined) and click the  icon (third row from the top) to toggle editing. Next, click  to the right of the toggle editing button to start drawing your new feature. Your mouse cursor will change to crosshairs and you can draw your property boundary (using the base map as guidance) by left clicking to add new vertices. Right click to finish drawing and add a feature I.D. number in the pop-up box. You can add more features (i.e., new points, polygons, or lines) to the same layer by repeating this process, or you can edit previous features using the vertex editor . With the vertex editor you can add, delete, or move the vertices (corners) of the polygon. Click the  button again to save your edits and exit editing mode. If you have a paper copy of a map with a property border, you can digitize the map into a raster through a process called georeferencing. You can then trace the boundary into a vector file using the steps above. Step-by-step instructions for georeferencing can be found at: https://docs.qgis.org/3.4/en/docs/training_manual/forestry/map_georeferencing.html.

Finally, you can create a property boundary layer by traveling the boundary in person with a GPS and uploading the file to QGIS. The following link contains instructions for transferring files from a GPS to QGIS: https://docs.qgis.org/3.4/en/docs/user_manual/working_with_gps/index.html.

You can change the appearance of a vector layer by double clicking on its name in the layers list to open up the **Symbology** menu. At the top of the pop-up will be an option called **Fill** and below it **Simple Fill**. Click on simple fill to open up more options for changing the fill and outline of the layer. Changing the appearance of a layer can help to increase contrast among layers or create a more visually appealing map. You can make a vector polygon transparent by choosing **No Brush** under the **Fill Style** drop-down menu.

Part 4. Supervised Land Cover Classification

At this point you should be familiar with the basics of accessing, visualizing, and downloading satellite imagery as well as some of the basic functions of QGIS. Now we will describe how to create a land cover map using the Semi-Automatic Classification Plugin (SCP) version 6.3.0.

The instructions are based on a case study from Alabama that focused on detecting and mapping Chinese privet, an invasive evergreen shrub, in a bottomland hardwood forest. The same steps will apply to other land cover mapping applications. For our example we will use Sentinel 2 imagery from early March. Our research and other studies have shown this is the most effective time frame for detecting privet because it is the time of year with the greatest spectral difference between privet and the deciduous overstory.

Step 1: Create Band Set

The first step in the supervised classification process is to combine the separate bands into a band set (also known as a band stack). Start by adding your imagery to QGIS using the steps detailed in Part 3. For Landsat 8 imagery, you need bands 2 to 7, and for Sentinel 2 imagery you need bands 2 to 8, 8A, 11, and 12. Next, click the  button (bottom row of the top banner) to open the SCP (figure 4). Click on the **Band Set** option on the left side of the dialogue box. Click on the  button to load your image bands. Highlight the bands by clicking on the first one, holding the shift key on your keyboard, then scrolling down and clicking on the last one.

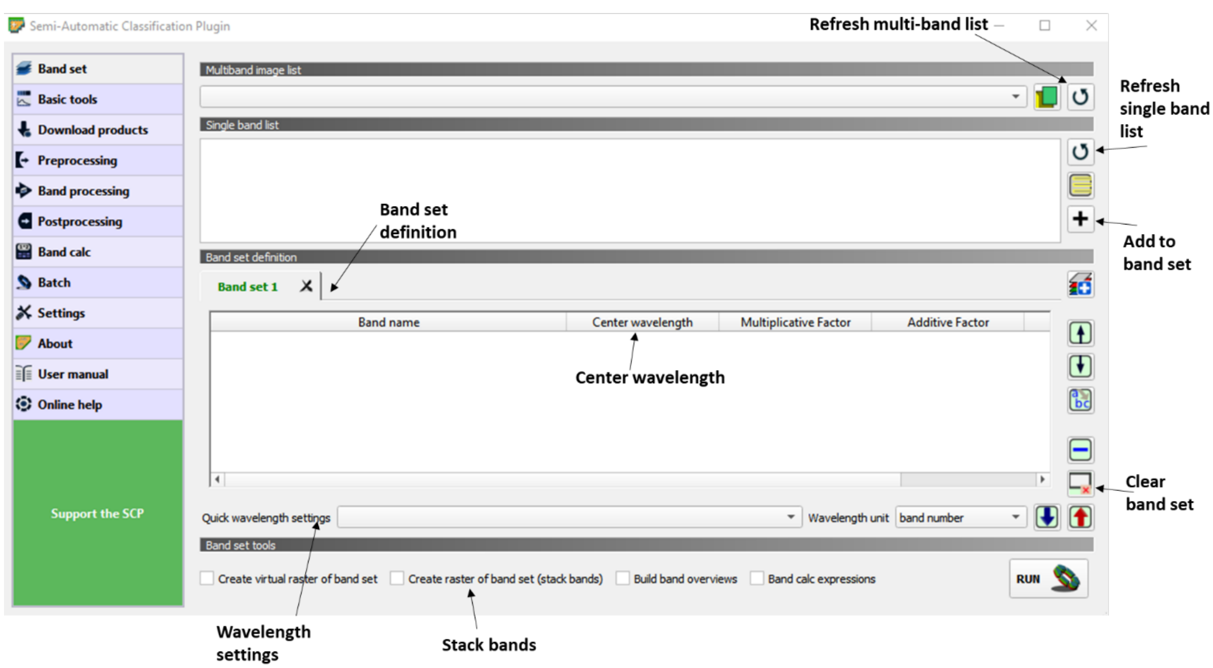


Figure 4. Band set tool in Semi-Automatic Classification Plugin

Once they are all highlighted in blue, click the button. All the bands should now be listed under the **Band Set Definition** section.

At this point you could continue working with the full Landsat or Sentinel scene, but doing so is computationally expensive and will take too long to run on most computers. To clip the image bands to your study site, click on the **Preprocessing** tab on the left side of the SCP menu. Scroll through the tabs at the top until you find **Clip Multiple Rasters**. Check the box next to **Use Vector for Clipping** and choose your property boundary vector file from the drop-down menu. The vector file needs to be loaded into the QGIS project (listed in your layers list) in order for it to show up (see Part 3).

You may need to click for it to appear. Click run then select a folder to save the clipped images in. The clipping process may take a few minutes.

Now go back to the band set page. Click to clear the previous (unclipped) band set and click to load the new clipped images into the single band list. These images should contain the prefix *clip*. Highlight the clipped images and add them to the band set using the button. Next, open the drop-down menu next to **Quick Wavelength Setting** and choose the satellite type you are using. This tells the software which wavelength to assign to each of the bands. Make sure the bands are listed under band set definition in the same order as the bands in the quick wavelength setting listing for your satellite. Next, check the box next to **Create Raster of Band Set (Stack Bands)** and click RUN. Your file explorer will pop up. Choose your project folder and click **Select Folder.** It may take a few minutes for the process to run. A new layer that ends in *B0stack_raster.tif* should now be present in your QGIS layers list. This raster layer is a multiband image stack that contains information from all of the image bands.

Go through the band set process one last time to add your new multiband stack image to the SCP. Clear the previous band set using the button. Click the button under **Multiband Image List**. Open the **Multiband Image List** drop-down menu and click on the band stack image.

The individual bands should now be loaded under the **Band Set Definition**. Make sure the **Quick Wavelength Settings** are set on the correct satellite. Check to make sure the center wavelengths for each band are correct. If they are listed as 1.0, 2.0, 3.0, etc., you can temporarily choose a different satellite under quick wavelength settings and then switch back to the correct satellite. This should cause the center wavelengths to change to the correct values. You do not need to press run again. Simply adding the new bands to the band set menu tells the SCP that those are the bands you will be working with.

The band numbers used to set band combinations in the SCP are based on the order of the bands in the band set definition menu, not the actual band numbers from the satellite. Because we are using only a subset of the satellite bands, the band numbers in the SCP don't line up with the real satellite band numbers. Table 3 shows the conversion between the SCP band numbers and the real Sentinel 2/Landsat 8 band numbers, assuming you are using the correct band order for each satellite from the quick wavelength settings.

Table 3. Band Number Conversions

SCP Band Number	Landsat 8	Sentinel 2
1	2	2
2	3	3
3	4	4
4	5	5
5	6	6
6	7	7
7	N/A	8
8	N/A	8A
9	N/A	11
10	N/A	12

You can now close the SCP menu to view your clipped band stack imagery. Find the 

tool in the fourth row of the QGIS banner at the top of your screen. Make sure the dark circle next to RGB is clicked (it will have a smaller grey circle inside). Type in a band combination (see table 3) and press **Enter** on your keyboard. It may take a few minutes for your computer to render the result. Note that colors may not appear how you would expect for a natural color combination. You can use the  and  buttons to the right of the RGB tool to increase color contrast in the image.

Step 2: Set Training Sites*

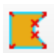
At this point you should have a clipped band stacked image of your property visible on the QGIS main screen. Your next step is to train the software to recognize the different land cover types on the property through the use of training sites (also called regions of interest or ROIs). You can either train the software to recognize all the main land cover types on the property (in which case every pixel in the image will be sorted into a land cover type during the classification step) or you can choose only one or a few land cover types to target (in which case pixels that don't match those land cover types will be assigned a "no data" value during the classification step). The latter technique requires setting spectral thresholds for determining when a pixel is too dissimilar from any of the target land cover types and is thus assigned a no data value.

Setting an appropriate threshold can be a trial and error process. For this tutorial we will map all primary land cover types on our property—uninvaded deciduous hardwoods, privet-invaded deciduous hardwoods, loblolly pine (*Pinus taeda*), swamp, open water, and fields—to avoid that step.

Find the SCP dock in the bottom left corner of your screen (below the layers list). If it is not there, click the  button to open it. Choose the **Training Input** tab on the left side of the dock (figure 5). Click the  button to create a new training file. Create at least three training sites per land cover type to capture the natural spectral variation within each. Each land cover type is

*In some cases you may need to classify more than one image, such as if your study area spans more than one Landsat or Sentinel scene or if you are working on a change-detection project. In such cases it is generally best to use a separate set of training sites (and thus separate training signatures) for each image due to variations in spectral properties across different acquisition dates (affected by atmospheric and orbital conditions). You can run each image segment through the classification process separately and combine the final maps for display or analysis. However, if you must use the same training signatures for multiple images, you need to use atmospherically corrected surface reflectance products.

considered a macroclass (MC), and each training site will have its own class (C).

To create the first training signature, add the appropriate land cover name in the MC info field of the SCP dock. You can add a class name as well, but it isn't necessary. Go to the bottom row of the QGIS top banner and click the  button. Draw a polygon around a relatively small area on the image that is representative of the land cover type you entered in the **MC Info** field. Left click to add new vertices; right click to close the polygon. Once you have finished drawing the polygon, click the save button in the SCP dock ().

To add another training site for the same land cover type, make sure that MC ID and MC info are the same as the last site but that the C ID is different (it should increase by 1 automatically). The C info field can be changed or left the same. Repeat this process until you have at least three training sites per land cover type. To start training sites for the next land cover type, increase the MC ID by 1 and change the land cover name for MC info. Repeat this process for all your land cover types.

You can use a few methods to aid in creating your training sites. The first and most obvious is on-the-ground knowledge. You can either rely on you prior experience/ familiarity with the property or conduct informal ground surveys to identify suitable training sites for each land cover type.

Another option is to visually interpret the Landsat/Sentinel imagery to select training sites (see Part 2). If you can't visit the property on foot and you have difficulty interpreting the multispectral imagery, you can also try using a high-resolution base map, such as Bing or Google imagery, for reference.

There is no set limit on how large or small your training polygons should be. If the polygon is too large you risk including pixels in the polygon that belong to a different land cover type. This can cause the spectral

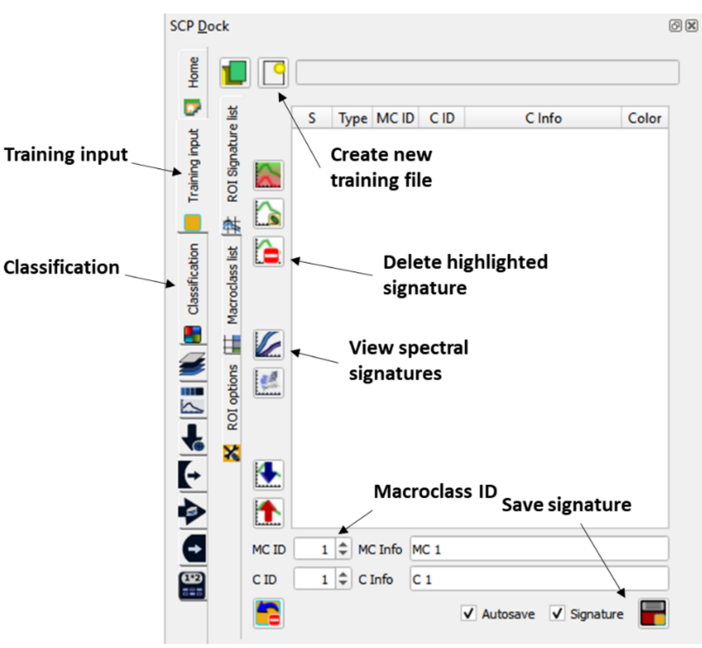


Figure 5. SCP dock training input page

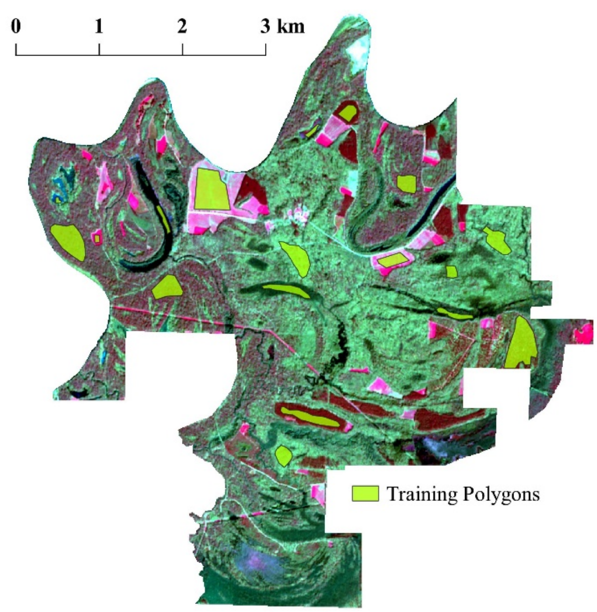


Figure 6. Training polygons for our example property are shown here in yellow on top of a false color infrared Sentinel image. When you create your own polygons they will appear dark grey.

signatures of the two land cover types to be too similar to each other and increase the classification error rate. If the polygons are too small you risk not capturing the full variation in spectral signatures. Additionally, you may get the following warning when using small polygons: “The following signature will be excluded if using Maximum Likelihood.” This means that the training polygon was too small for the software to gather enough information on the variability of the spectral signatures of the pixels within the polygon; thus, the Maximum Likelihood classifier can’t use the information from that polygon. See figure 6 for a map of the training polygons used in our case study.

You also can set training signatures using the button and a region-growing algorithm, although that technique won’t be covered in this guide.

Step 3: Classify Land Cover

In this step, the software will calculate the spectral signature of each pixel in the image, compare that spectral signature to the training signatures set in the last step, and sort the pixel into the land cover class that is the best fit.

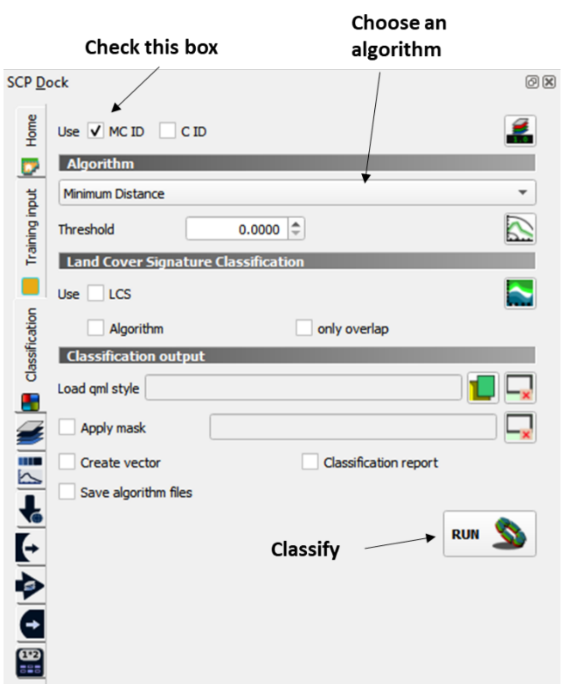


Figure 7. SCP dock classification page

Click on the **Classification** tab on the left side of the SCP dock (figure 7). At the top of the menu, make sure that the box next to MC ID is checked. Below that is the **Algorithm** section. Use the drop-down menu to select between three different options: minimum distance, maximum likelihood, and spectral angle mapping. These three options are essentially different ways of defining which land cover type is the best fit for each pixel (i.e., which one has the most similar spectral signature). Alternatively, a minimum threshold for spectral similarity can be used, although we won’t cover that in this tutorial. With no threshold, every pixel in the image will get classified into the most similar land cover type, even if the best fit is still fairly different.

Below the algorithm section is a section called **Land Cover Signature Classification**. This is essentially another type of classification algorithm. This algorithm sorts pixels into a land cover type only if its signature falls completely within the range of spectral signatures from the training polygons of a single land cover type. If it falls outside the spectral range of one of the land cover types or if it falls within the range of multiple types, the pixel is left unclassified. You can click the box next to **LCS** to activate this classification mode. Checking the box below it (next to **Algorithm**) tells the software to revert to using whichever algorithm is selected in the drop-down box for pixels that are unclassified by the LCS algorithm. Selecting the **Only Overlap** box tells the software to only use the backup algorithm for pixels with spectral signatures that overlap multiple cover types. Pixels that don’t match any of the land cover types are left unclassified.

There is no universal best algorithm. The one that performs best in a given situation will depend on the spectral characteristics of the land cover types being mapped (figure 8). For this reason it is typically best to experiment with several algorithms to identify the best choice. The SCP makes this easy via the preview function.

Once you've set up the classification algorithm options, go to the bottom row of the QGIS top banner and click the  button and then click on your map. This will create a temporary file with a preview of the land cover classification produced by the settings you've chosen. You can increase or decrease the size of the preview box using the arrows next to the **'S'** field to the right of the preview button (the default is 200 pixels). You can change your classification settings and then click  to rerun the preview. Click  to remove the previews. You can use this technique to visually assess the accuracy of the land cover map produced by each classification algorithm and choose the one that best fits your needs.

Once you are satisfied with the classification previews, you can click  to produce a permanent file. If none of the algorithms produce useful results, you may need to go back to step 2 and modify your spectral signature training polygons. It is possible that you accidently mislabeled one of your training polygons, created a training polygon that included multiple land cover types, created a land cover type that was too broad (i.e., there was too much spectral variation), or missed an important land cover type altogether.

Step 4: Complete an Accuracy Assessment

At this point you should have a classified land map that appears fairly accurate based on your informal visual assessment. The last step is to complete a formal accuracy assessment. How much time and resources you spend on this step will depend on your planned uses for the map. If you plan on

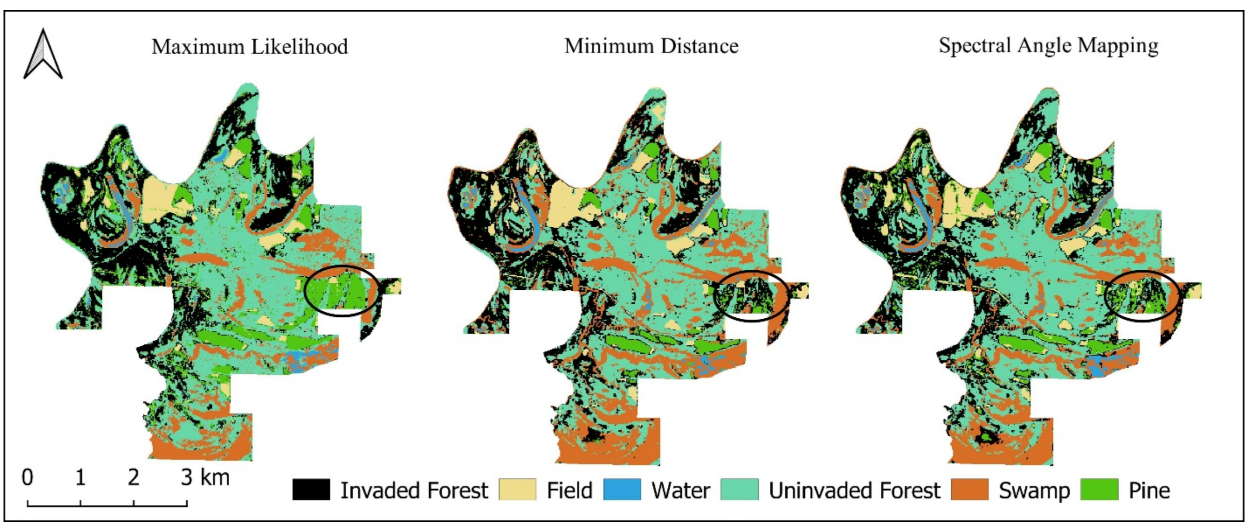


Figure 8. Land cover maps produced by three different classification algorithms applied to the same Sentinel 2 image. All three maps highlight the same general area as invaded by privet (black); however, there is a notable difference on the east side of the property. The circled area is a low-density pine stand with little privet cover, but the minimum distance and spectral angle algorithms mislabeled significant portions as privet-invaded hardwood forest. The best algorithm for a different property and set of land cover types will likely vary.

using acreage estimates and/or location information from the map as an integral part of planning or monitoring a management program, you need to put considerable effort into verifying the accuracy of your map.

There are many techniques available for conducting accuracy assessments. Remote sensing professionals may disagree over which technique is best suited for a given project. In this section we will provide an introduction to the basics of accuracy assessments along with links to several tools and associated tutorials that can be used to assess accuracy in slightly different ways.

Most accuracy assessments are conducted through (1) randomly sampling a portion of your study area, (2) assessing the true land cover within that random sample, and (3) comparing the true land cover (also known as the reference data) to the land cover predicted by your classified land cover map. The accuracy statistics derived by comparing the randomly sampled reference data to the land cover map are assumed to be representative of the accuracy of the entire map.

The random samples of your study area may be single points (representing single pixels) or a larger grid/polygon. Random points may be easier to generate and sample in the field, but there is an important limitation. All GPS devices have a certain amount of location error, and in recreational-grade GPS devices this error can be 10 or more meters. Additionally, the satellite imagery itself will have some amount of error in its location data. Combined, these two sources of location error can make it difficult to navigate to a point on the ground that aligns with a specific pixel.

If your reference data and map data don't line up spatially, your accuracy statistics will be unreliable. For this reason it may be better to assess accuracy using larger grids or polygons. There is no set rule for the number of samples you should use, although a minimum of 50 per land cover class has been suggested as a general guideline.

Once you've established your random sample of points or polygons, there are several ways to assess their true land cover. One option is to use a GPS to navigate to the samples on the ground and assess the land cover in person. This can be time-consuming but may be the most reliable method, assuming you have access to a GPS with adequate location accuracy. You could also assess your samples using high-resolution imagery such as from the NAIP.

When using moderate resolution imagery, such as Landsat and Sentinel, there may be occasional mixed pixels in which two or more land cover types are present within the pixel. Whichever land cover makes up the majority (greater than 50 percent cover threshold) of the pixel (or polygon if using larger sampling units) is usually the best choice for labeling the sample. However, if you are specifically interested in detecting a certain land cover type (for example, an invasive plant species), you could try experimenting with several cover thresholds to identify the smallest threshold at which the land cover of interest can be reliably identified. The cover threshold at which a specific land cover type can be reliably identified will be affected by your training areas, so if your goal, for example, is to detect an invasive plant at low densities, you should have training areas that reflect that.

Once you've finished collecting your reference data, you can compare it to the land cover map to produce accuracy measurements. Remote sensing specialists have developed many ways of defining accuracy, many of which are based on an error matrix (also known as a confusion matrix). See Congalton 1991 for more information on error matrices.

The SCP has a built-in accuracy assessment function. A step-by-step tutorial is available at https://fromgistors.blogspot.com/2014/09/accuracy-assessment-using-random-points.html?spref=yml.

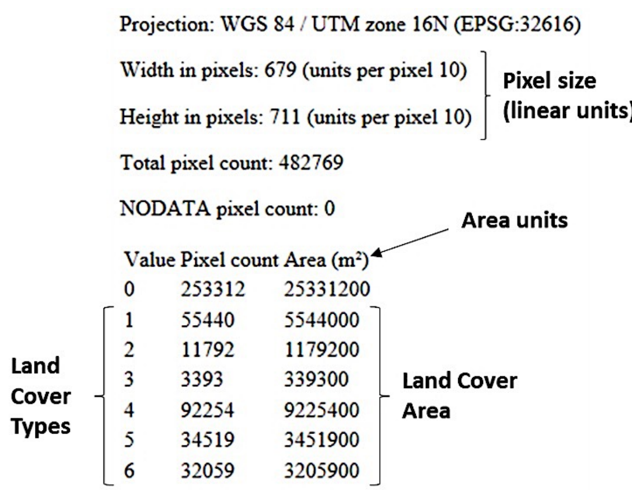
There is also a stand-alone plugin for QGIS called AcATaMa (Accuracy Assessment of Thematic Maps) that is built to simplify accuracy assessments, including the generation of random points, reference data collection, and analysis. Documentation and a tutorial for this plugin can be found at https://smbyc.github.io/AcATaMa/.

Step 5: Estimate Surface Area

Once you've developed a land cover map with adequate accuracy for your project, the last step is to estimate the surface area of the land cover types that you mapped. Click on the **Processing** tab at the top of the QGIS interface and choose **Toolbox**. This should open a list of options on the right side of your screen. Choose **Raster Analysis Then Raster Layer Unique Values Report**.

Use the drop-down menu under **Input Layer** to select your classified map. Click **Run** at the bottom of the menu. A blue link should appear at the bottom right of the QGIS interface. Click on this to open your report (figure 9). The numbers listed under **Value** correspond to your land cover types, although the value labeled as '0' may be a no data value from the outline of your property (likely shown in black on your map). Pay attention to the area units, which will be dependent on the projection of the raster layer.

Alternatively, the AcATaMa plugin provides area estimates for land cover types with confidence intervals (a measure of uncertainty) based on your accuracy assessment. This can be extremely useful when interpreting map outputs in the context of management decisions.



Projection: WGS 84 / UTM zone 16N (EPSG:32616)

Width in pixels: 679 (units per pixel 10)

Height in pixels: 711 (units per pixel 10)

Total pixel count: 482769

NODATA pixel count: 0

Value	Pixel count	Area (m^2)
0	253312	25331200
1	55440	5544000
2	11792	1179200
3	3393	339300
4	92254	9225400
5	34519	3451900
6	32059	3205900

Figure 9. Raster layer unique values report

Part 5. Additional Resources and References

This guide provided a very basic introduction to satellite imagery analysis and related functions in QGIS. There are many additional tools available within the SCP and QGIS. The following web links and publication citations are good resources for expanding your GIS and remote sensing–related knowledge and skill sets. Some of these resources have already been referenced in this guide, while others are new.

Additional Resources

Satellite Imagery Access

Sentinel Hub EO Browser:
https://apps.sentinel-hub.com/eo-browser/

USGS EarthExplorer:
https://earthexplorer.usgs.gov/

ESA Copernicus Open Access Hub:
https://scihub.copernicus.eu/dhus/#/home

Software Downloads

QGIS:
https://qgis.org/en/site/forusers/download.html

7-Zip: https://www.7-zip.org/download.html

General Tutorials and User Guides

QGIS Documentation:
https://qgis.org/en/docs/index.html

QGIS User Forum:
https://gis.stackexchange.com/questions/tagged/qgis

Semi-Automatic Classification Plugin Tutorials:
https://fromgistors.blogspot.com/p/semi-automatic-classification-plugin.html

Landsat 8 User Guide:
https://www.usgs.gov/media/files/landsat-8-data-users-handbook

Sentinel 2 User Guide:
https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi

Specific Topics

Creating and Exporting Professional Maps:
https://docs.qgis.org/3.4/en/docs/training_manual/map_composer/index.html

Coordinate Reference Systems:
https://docs.qgis.org/3.4/en/docs/gentle_gis_introduction/coordinate_reference_systems.html

Using Projections in QGIS:
https://docs.qgis.org/3.4/en/docs/user_manual/working_with_projections/working_with_projections.html

QGIS and GPS Data:
https://docs.qgis.org/3.4/en/docs/user_manual/working_with_gps/index.html

Georeferencing:
https://docs.qgis.org/3.4/en/docs/training_manual/forestry/map_georeferencing.html

AcATaMa plugin documentation (accuracy assessments):
https://smbyc.github.io/AcATaMa/

SCP classification accuracy assessment tutorial:
https://fromgistors.blogspot.com/2014/09/accuracy-assessment-using-random-points.html?spref=yml

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