Mapping Weed Infestations Using Remote Sensing

Introduction

In certain circumstances, some weeds can be mapped faster and more economically using remote sensing than using traditional ground survey methods. However, remote sensing is not always the best option. It is critical to understand the limitations of the technology and determine whether remote sensing is the best choice for your weed and specific circumstances. If you have not made this determination yet, please refer to the document titled "What Weeds can be Remotely Sensed?" in *A Weed Manager's Guide to Remote Sensing and GIS.*

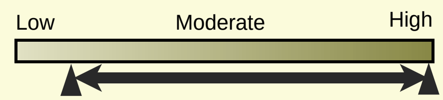
Once you have determined that remote sensing is a good choice for your particular circumstances, this document will guide you through the basic steps involved in mapping weeds using remote sensing.

QUICK LOOK

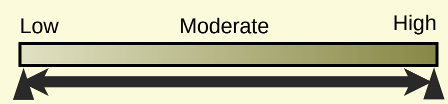
Objective:
This document provides basic guidelines for mapping weeds using remote sensing (aerial or satellite imagery). Concepts covered include:

- Selecting the proper sensor and resolution
- Collecting ancillary field data
- Analyzing the imagery
- Conducting an accuracy assessment

Cost:



Expertise:



IMPORTANT

Remote sensing is typically best suited for mapping relatively large geographic areas. The cost of remote sensing is related to economies of scale — the larger the survey area, the cheaper the cost per acre.

Major Steps

1. Establish objectives and plan how to achieve the objectives.
2. Select the appropriate resolution, type of imagery, and vendor.
3. Collect ancillary field data.
4. Analyze the imagery.

Establish Objectives & Plan How to Achieve Objectives

The first steps to successful weed mapping using remote sensing are establishing clear objectives and planning carefully in order to achieve those objectives. The objectives will determine to a large extent the resolution and sensor used to collect the imagery. In addition, the specific weed and survey area will determine when the data should be collected and whether they should be collected on more than one date. As you define your objectives and plan, consider the following questions:

- What is the smallest patch size that *must* be mapped?
- At what density can weed patches be ignored for mapping purposes?
- What level of accuracy is acceptable?

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- At what time(s) of year will your weed be most distinct from its surroundings?
- Will the time of appearance of distinguishing traits vary by location?
- How large is the area you wish to map?
- What is your remote sensing expertise and what expertise is available?

Select the Resolution, Type of Imagery, and Vendor

There are many choices in acquiring remotely sensed data. The major choices are in regard to:

- Spatial resolution
- Spectral resolution
- Type of imagery/photography

The imagery characteristics and specific type of imagery selected for a particular application will ultimately arise from a compromise among resolution, cost, available expertise, and personal preference.

IMPORTANT

Imagery spatial resolution should be one-fourth the size of the smallest weed patches to be mapped.

Select the Appropriate Spatial Resolution

The imagery resolution required to map a weed infestation is dependent on the smallest patch size that must be mapped. Specifically, the pixel size of the imagery should be at least one-fourth the area of the smallest patches that need to be mapped. This is because the placement of the pixel boundaries will not necessarily line up with the boundaries of the weed patches. Pixels covering part of a weed patch and part of an uninfested area will generally be identified as uninfested when the data are analyzed. This leads to "missed" patches (figure 1).

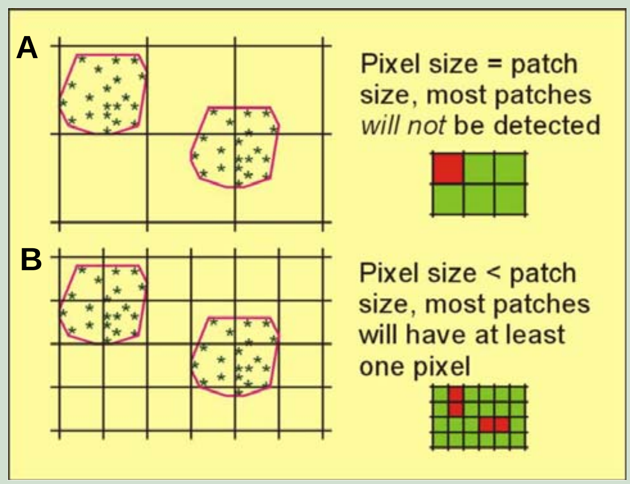

Figure 1—*(A)* When weed patch size is the same as the pixel size, most patches will not be detected (grids represent imagery pixels). *(B)* If pixels are at least one-fourth the size of the patches, most patches will be properly identified. Red cells in the grids to the right indicate the pixels where weeds were identified in the imagery.

Select the Appropriate Spectral Resolution

Spectral resolution refers to the number and width of spectral bands of a particular sensor. In general, the greater the spectral information (i.e., more bands), the greater the ability to distinguish weeds from their surroundings and the greater the accuracy. However, increased spectral information must be weighed against cost, turnaround time, and ease of processing. Higher spectral resolution data are more

What about Hyperspectral Imagery?

In general, with increased spectral resolution, you can expect increased accuracy and an increased ability to map weeds that are spectrally similar to their surroundings. However, high spectral resolution (hyperspectral) imagery is currently difficult to process, requires expertise in image processing, and almost always exceeds Forest Service budgetary constraints. Nevertheless, in the future, the price of hyperspectral imagery is expected to decrease and the ease of processing increase. If and when this happens, many new possibilities for weed mapping will be available.

Table 1—Comparison of different types of remotely sensed data.

Platform	Type	Spatial Resolution	Spectral Resolution	Relative Cost†	Advantages	Disadvantages
Aircraft	Film Photography	Very high	Low	$$$$	• Familiar to resource managers • Readily available • Color infrared available	• Not digital • May need to scan & rectify • Spectral purity may be lost • Film must be developed
	Digital Photography	Very high	Low	$$	• Digital • Quick turnaround	• May need to rectify • Generally no color infrared
	Digital Videography	High	Low	$$	• Quick turnaround	• Lowest spatial resolution of the airborne data • Rectification may be difficult
	Multispectral Scanner	<5m	<15 bands	$$$$	• Digital • Good spectral quality	• May need to rectify • Rectification may be difficult
	Hyperspectral Imagery	<5m	>100 bands	$$$$$	• Most accurate • Can potentially map more species	• Very expensive • Difficult to process • Large storage requirements • Rectification may be difficult
Satellite	High Resolution Imagery*	<5m	<=4 bands	$$$	• Large area coverage compared to airborne imagery • Easier to rectify than aerial imagery	• Covers small areas compared to other satellite imagery • Potential for cloud cover • May be difficult to acquire data when needed • Data must be tasked
	Moderate Resolution Imagery**	<=20m	<=4 bands	$$	• Large area coverage	• Potential for cloud cover • Low spatial resolution • Data must be tasked
	Moderate Resolution Imagery***	<=60m	<=7 bands	$	• Inexpensive • Large area coverage • Imagery continuously acquired	• Low spatial resolution • Potential for cloud cover

† $< $500, $$ < $1000, $$$ < $2000, $$$$ < $4000, $$$$$ < $10,000; cost based on 100km^2.
*Quickbird, IKONOS
** SPOT 4 and 5, IRS LISS, etc.
***Landsat TM, IRS AWiFS, etc.

expensive and can be very difficult to process. The turnaround time for very high spectral resolution imagery, known as hyperspectral imagery (typically > 100 bands), is frequently long.

Film-based and digital aerial photography both have relatively low spectral resolution. However, these types of data are less expensive, have a quick turnaround time, and are much easier to process. Table 1 compares the spectral resolution and other characteristics of various types of imagery.

Weeds having biological characteristics that readily distinguish them spectrally from the surrounding vegetation can be good targets for lower spectral resolution imagery. Higher spectral resolution imagery will be needed to map weeds that are spectrally similar to the surrounding vegetation. Although hyperspectral imagery can be used to map weeds that cannot be mapped with lower spectral resolution imagery, it is currently not recommended for most Forest Service applications because of the cost, slow turnaround time, and difficulty of processing.

Select the Type of Imagery/Photography

The required spatial and spectral resolutions will determine to a large extent the type of imagery collected. However, for particular spatial and spectral resolutions, there will likely be several options for how the imagery is collected and the spectral content of the imagery. The primary decisions to be made include selecting:

- Film-based photography or digital imagery
- Spectral content
- Airborne or satellite imagery

Film-based photographs versus digital imagery

There are two major methods of collecting image-based data for weed mapping—film-based photography and direct acquisition of digital imagery. Types of digital imagery range from photographs taken with a digital camera to imagery collected with a multispectral or hyperspectral scanner. Although there are benefits and disadvantages to both film-based photography and digital imagery (table 1), the benefits of digital imagery often outweigh the benefits of film-based photography. For additional discussion, refer to the box at left.

Why Not Film-Based Photography?

There are three main reasons for recommending digital imagery over film-based photography. First, digital imagery may contain more spectral information (> 3 bands) than conventional photos. The additional spectral information can aid in identifying weed patches. The second reason is to save time, and the third is to eliminate sources of error. The Forest Service and most other agencies require weed maps to be in a digital format for entry into a GIS database. Converting hand-drawn polygons on an aerial photo to digital format is time consuming and can lead to errors. Alternatively, scanning, rectifying, and processing the photos by computer is also very time consuming. In addition, when aerial photos are scanned, spectral integrity is lost, potentially leading to lower classification accuracy.

Spectral content

For film-based photography, both true color and color-infrared (false color) photos can be taken. In general, plant species are more easily distinguished on color-infrared photographs. However, some weeds (e.g., saltcedar with fall coloration) may be identified more readily using true color imagery.

If digital imagery is selected, there are several types of imagery to choose from (table 1). Higher spectral resolution data are, of course, more expensive and may be more difficult to process. Digital camera imagery is relatively inexpensive and easy to process, but generally only has three spectral bands, which are usually red, green, and blue. Nevertheless, the Forest Service and some vendors have digital cameras that collect imagery with red, green, and near infrared (NIR) bands. A few vendors provide four-band (red, green, blue, and NIR) imagery.

Before making a decision on the spectral content to capture, it is advisable to check to see what types of imagery others have used to map the same weed, or a similar species.

Airborne vs. satellite imagery

Digital imagery can be acquired from either aircraft or satellite platforms (figure 2). Both methods have advantages and disadvantages (table 1). In general,

Will I Need to Rectify My Imagery If The Vendor Provides It Rectified?

Commercial imagery (both satellite and airborne) may be purchased already registered to a map (i.e., rectified and georeferenced), but the image registration usually needs to be improved using ground control points (GPS locations of easily identifiable point features). If airborne imagery is collected over large areas, collecting ground control points and improving the registration of each image becomes very tedious, time consuming, and expensive.

TIP

Acquiring Imagery: *(Forest Service users) For detailed guidance on how to acquire various types of imagery, refer to the* Forest Service Image Acquisition Handbook *(available online: http://fsweb.rsac.fs.fed.us/documents/2999-MAN1.pdf). The handbook reviews various types of imagery and identifies imagery sources, agency contacts, availability, and costs.*

satellite imagery is better suited for large, contiguous survey areas, while airborne imagery is better for smaller or noncontiguous areas. High-resolution satellite imagery (which is usually required for weed mapping) is expensive, but the cost per acre decreases with increased area coverage. Therefore, satellite imagery may be too expensive for small survey areas, but can be reasonable for large, contiguous areas.

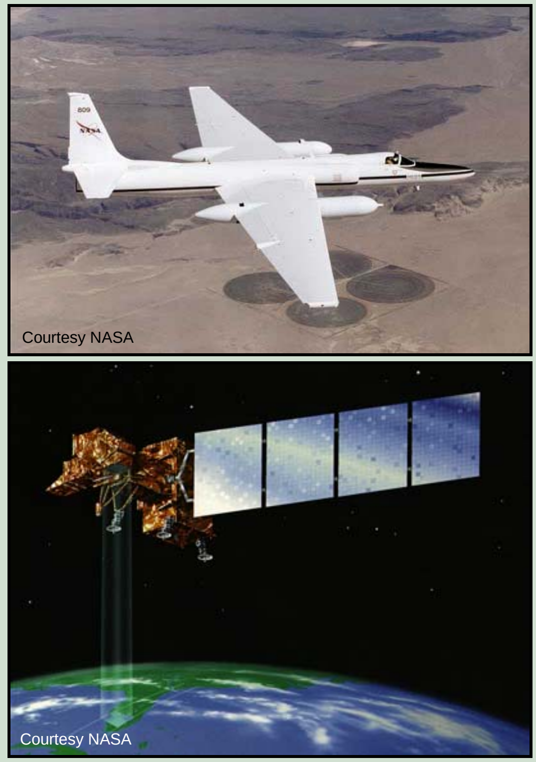

Figure 2—Digital imagery can be acquired from *(A)* aircraft or *(B)* satellite platforms.

Satellite imagery covers a relatively large geographic area compared to airborne imagery. In addition, airborne imagery is continually affected by changing pitch, yaw, and roll of the aircraft whereas satellite imagery is not. Because of the small area coverage of airborne data and the effects of continuous change in the attitude of the aircraft on the imagery, the time and expense involved in rectifying and processing airborne imagery for large areas can be substantial.

One disadvantage of satellite imagery is that it can sometimes be difficult to acquire the data when needed. A satellite has only one chance every few days to acquire imagery over a particular location. If weather conditions are not ideal when the satellite passes over, the acquisition can be delayed for weeks. In addition, other customers' imagery requests can take priority over your request, further delaying the acquisition. Airborne imagery, on the other hand, can be collected anytime the sun is sufficiently high in the sky and on any day. Furthermore, there are far more vendors of airborne imagery than satellite imagery to choose from. Currently, there are only two commercial satellites that acquire high-resolution imagery (table 2). If your window of opportunity is very narrow, airborne imagery may be the safer option.

Table 2—Specifications of high resolution commercial satellites.

Satellite	Company	Spatial resolution	Bands	Scene size
QuickBird	DigitalGlobe www.digitalglobe.com	0.61m panchromatic 2.40m multispectral	4 (red, green, blue, NIR)	16.5x16.5km
IKONOS	Space Imaging www.spaceimaging.com	1m panchromatic 4m multispectral	4 (red, green, blue, NIR)	11.3x11.3km

CAUTION

Do NOT attempt to use weed patch polygons having variable weed cover for training for image classification. Low accuracy would be the likely result.

Collect Ancillary Field Data

Field data must be collected to use remote sensing effectively for management objectives. The field sites provide training data for supervised and feature extraction classification. They also provide data for accuracy assessment. There are many types of data collected in the field. Generally field crews with a global positioning system (GPS) are sent to identify locations of invasive weeds. These data, collected for the purpose of weed management, can be either point data for single weeds or polygons around patches of weeds. Both types of data can be used in a geographic information system (GIS) for planning weed control measures.

Unfortunately, the percent cover of the weed-control polygons collected by field crews is generally not known and not constant. Therefore, these polygons are usually not useful for training image classification software or for accuracy assessment. Other polygons that have uniform and consistent weed cover (figure 3) must be created. The cover of the invasive weed and the type of co-occurring vegetation need to be recorded. Polygons of the co-occurring vegetation, without the invasive weed, also need to be created.

For accuracy assessment, the general rule of thumb is that at least 50 polygons of each class should be obtained (if possible) for statistical purposes. If there is only one vegetation cover type, then 50 polygons with the invasive weed and 50 polygons without it should be obtained. Additional polygons will be needed to train the image classification software.

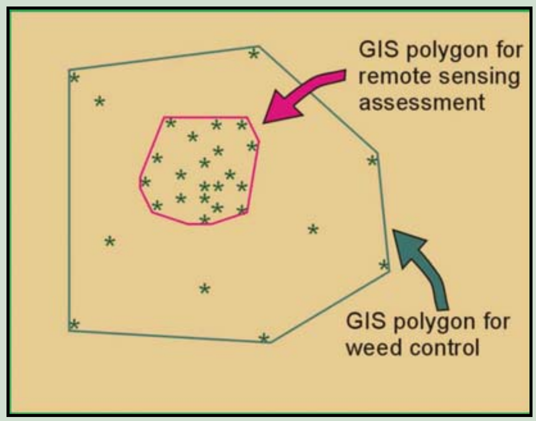

Figure 3—Polygons of weed patches collected for management purposes are generally not helpful for remote sensing because the weed cover is not uniform within the polygon. Additional polygons having uniform weed cover are needed.

When training and accuracy assessment polygons are collected, the accuracy of the GPS must be adequate for the resolution of the imagery. Weed patch size determines both the spatial resolution of the remote sensing system and the accuracy requirements of the GPS units used to collect the field data. The GPS must have an accuracy of less than one-half the size of the pixel. Thus, a personal GPS enabled with Wide Area Augmentation System (WAAS) that has 4-5 meter accuracy will be fine for moderate-resolution satellite imagery such as Landsat (30 meter) or SPOT (10–20 meter) imagery, but will not be adequate for QuickBird, IKONOS, or high-resolution airborne imagery. For many weed mapping applications, differential GPS with sub-meter accuracy will be required.

Analyze the Imagery/Photography

There are many methods of image analysis. If one method does not work well, perhaps another method will. The goal is to get the most useful map of invasive weeds (i.e., high user and producer accuracies—described in the next section). Some methods you might consider include:

- **Image Interpretation—**Image interpretation is an art that has traditionally produced high accuracies. The interpreter uses many different criteria—shape, color, texture, shadow, and context—on a photograph or a three-band image displayed on a computer screen to identify weed patches. The aerial photographs or digital images are usually natural color (red, green, and blue) or false color infrared (near infrared, red, and green) with high spatial resolution. One drawback to image interpretation is that there may be large differences between interpreters when classifying the same image. In addition, interpretation requires considerable time and effort.

- **Supervised Classification—**Supervised classification uses the spectral characteristics of training areas to group together similar pixels based on some algorithm (e.g., minimum distance, maximum likelihood, spectral angle, etc.). Most studies use some sort of supervised classification to map invasive weeds. A variety of supervised methods are found in all image processing software packages.

- **Unsupervised Classification—**Unsupervised classification allows the computer to group together pixels with similar spectral characteristics. The idea is that pixels with the invasive weed would group together naturally into one or two classes. Most studies use unsupervised classification for image exploration rather than for generating the final map.

- **Feature Extraction—**Feature extraction, or object oriented classification, uses both spectral and contextual (spatial) information to identify similar features. The identified features are delineated with polygons. In the case of weeds, polygons would enclose weed patches. Feature extraction could be thought of as an automated version of image interpretation.

  Two software packages that perform object oriented classification are Feature Analyst (Visual Learning Systems) and eCognition (Definiens Imaging). Feature Analyst is an extension for ERDAS Imagine and ArcGIS. This package is relatively easy to use, and can produce exceptional results. eCognition is a quick and powerful package that can also produce exceptional results, but has a steep learning curve.

IMPORTANT

Forest Service Users: *ERDAS Imagine (Leica Geosystems) is the corporate image processing suite used by the Forest Service.*

Assess the Accuracy of the Map

Following classification, an accuracy assessment should be performed to determine if the classification (map) of invasive weeds meets management objectives. Without delving into extensive statistics, there are three basic measures of accuracy:

- Overall accuracy
- Producer's accuracy
- User's accuracy

These three measures are derived from an error matrix containing a class-by-class comparison of the image analysis predictions and the field data for specific test locations (figure 4).

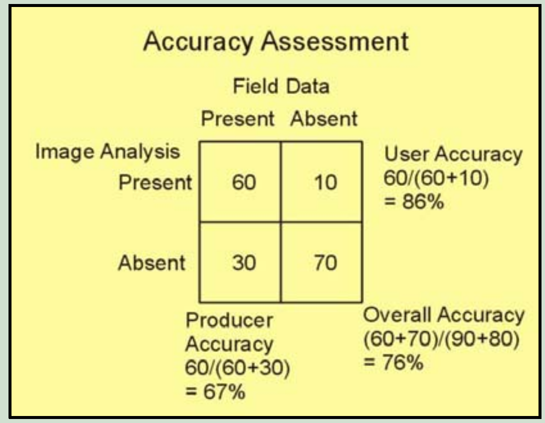

Figure 4—Error matrix used for assessing the accuracy of a classification. Calculations of the overall, user's, and producer's accuracies are shown.

Overall accuracy—Overall accuracy is the sum of correct predictions (diagonal squares in the matrix) divided by the total number of observations. If there are a large number of weed-absent test sites compared to weed-present sites, then the overall accuracy will be high even though the usefulness of the map may be low.

Producer's accuracy—Producer's accuracy is calculated by dividing the number of weed locations correctly predicted (the upper left hand cell) by the total number of field sites containing weeds (the column total). This measure shows how well the remote sensing system detects the invasive weed species on the ground. Therefore, only the field data polygons with weeds present are used in the calculation. If the threshold weed-cover needed for detection is higher than the cover measured in the field, then the producer accuracy will be low.

User's accuracy—Looking at a specific pixel classified as weeds present, the user's accuracy will show the probability that weeds are actually present; hence, only the weed-present pixels classified on the image are used in this calculation. User's accuracy is calculated by dividing the number of weed locations correctly predicted (the upper left hand cell) by the total number of sites predicted to have weeds (the row total). User's accuracy indicates how distinctive the weeds are from the co-occurring vegetation. Therefore, for highly distinctive weeds, the user accuracy is generally high.

ASSISTANCE?

For more information or assistance, please contact

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