

9: PREDICTING SEAGRASS STANDING CROP FROM SPOT XS SATELLITE IMAGERY

Aim of Lesson

To learn how to derive a map of seagrass standing crop from a SPOT XS or similar appropriate image.

Objectives

1. To understand the importance of field survey and the methods used to calibrate imagery and thus allow seagrass standing crop to be estimated.
2. To investigate the relationship between seagrass standing crop and the single depth-invariant “bottom index” image derived from SPOT XS bands #1 and #2 (green and red wavebands) using field survey data referenced to UTM coordinates.
3. To learn how to mask out non-seagrass areas of the SPOT XS depth-invariant image.
4. To learn how to construct a palette to display seagrass standing crop densities effectively.
5. To analyse the image in order to estimate areas of dense, medium and sparse seagrass.

Introduction

Ecologists and managers of seagrass systems may require a range of data on the status of seagrass habitats. Those seagrass parameters that can be measured using remote sensing are listed in Table 9.1.

Table 9.1. Seagrass parameters which can be measured using optical remote sensing. MSS = multispectral scanner, CASI = Compact Airborne Spectrographic Imagery, TM = Thematic Mapper.

SEAGRASS PARAMETER	SENSOR	AUTHORS
Boundaries of seagrass beds	Aerial Photography	Greenway and Fry, 1988; Kirkman, 1988; Robblee <i>et al.</i> , 1991; Ferguson <i>et al.</i> , 1993; Sheppard <i>et al.</i> , 1995
	Landsat TM	Lennon and Luck, 1990
Seagrass cover (semi-quantitative)	Airborne MSS	Savastano <i>et al.</i> , 1984
	Landsat TM	Luczkovich <i>et al.</i> , 1993; Zainal <i>et al.</i> , 1993
	SPOT XS	Cuq, 1993
Seagrass biomass/standing crop	Landsat TM	Armstrong, 1993
	CASI, Landsat TM, SPOT XS	Mumby <i>et al.</i> , 1997b

Of the studies listed in Table 9.1, the most detailed obtained a quantitative empirical relationship between seagrass standing crop (biomass of above-ground leaves and shoots) and remotely sensed imagery (Armstrong, 1993; Mumby *et al.*, 1997b). Standing crop is a useful parameter to measure because it responds promptly to environmental disturbance and changes are usually large enough to monitor (Kirkman, 1996). The methods used to map seagrass standing crop are explored in this lesson.

Essentially, this involves five stages:

1. Measurement of seagrass standing crop in the field.
2. Relating seagrass standing crop to remotely-sensed image data using linear regression. The regression equation represents the calibration of imagery to seagrass standing crop and the coefficient of determination (r^2) indicates how much of the variation in standing crop is explained by the remotely-sensed data.
3. Using the regression equation to convert (calibrate) the image data in each pixel to seagrass standing crop (g. m^{-2})
4. Masking out land and non-seagrass habitats to leave a map of seagrass standing crop.
5. Assignment of a colour palette to standing crop for easy visual interpretation.

Background Information

This lesson relates to material covered in Chapters 12 and 16 of the *Remote Sensing Handbook for Tropical Coastal Management* and readers are recommended to consult these for further details of the techniques involved. This lesson describes an empirical approach to mapping seagrass standing crop using SPOT XS. The seagrass was located on the Caicos Bank in shallow (<10 m deep) clear water (horizontal Secchi distance 20–50 m) and was dominated by the species *Syringodium filiforme* (Kützting) and *Thalassia testudinum* (Banks ex König).

The Bilko 3 image processing software

Familiarity with *Bilko 3* is required to carry out this lesson. In particular, you will need experience of using Formula documents to carry out mathematical manipulations of images and Histogram documents to calculate the area of particular features on the imagery. These features are covered in Tutorials 10 and 4 respectively of the *Introduction to using the Bilko 3 image processing software*. A familiarity with *Excel* is also desirable.

Image data

This lesson will use a SPOT XS image of the Caicos Bank as this imagery covers a large area while having a reasonably high spatial resolution (20 m^1). To obtain a quantitative relationship between image data and seagrass standing crop, it is important to compensate for the effects of variable depth. Therefore, the image you are provided with has undergone the depth-invariant processing described in Lesson 7 of this module. SPOT XS bands #1 (green) and #2 (red) were processed to form a single depth-invariant bottom index band and you are provided with a subset of the Caicos Bank showing South Caicos (file ***SPOTXS_depth-invariant.dat***). This is a 32-bit floating-point file where each pixel value is represented by a real number stored in four bytes. To illustrate the importance of compensating for variable depth; when seagrass standing crop was regressed on reflectance (**not** corrected for depth), the coefficient of variation (r^2) ranged from 0.05 to 0.32 for SPOT XS (and was similarly low for other sensors). These values are too low for adequate prediction of seagrass standing crop.

You are also provided with two mask files. The first is a land mask (***Landmask_lesson9.gif***) in which all land pixels are set to zero and all submerged pixels are set to a value of 1. When another image is multiplied by the land mask, all land pixels are set to zero whilst submerged pixels are unaffected. The second mask removes all non-seagrass habitats in the imagery (***Seagrass_mask.gif***). This was created from an image of coral reef, algal, sand and seagrass habitats. Land, coral reef, sand and algal pixels were set to zero leaving only seagrass habitats set to a value of 1.

¹ Note that the SPOT-5 High Geometric Resolution (HRG) sensor (launched in 2002) offers 10 m resolution multispectral data.

Field survey data

A variety of techniques exist for measuring seagrass standing crop including destructive and non-destructive approaches. We recommend non-destructive methods because they allow repeated monitoring, are less harmful to the environment and are generally faster than destructive methods. Good general texts on seagrass sampling include Unesco (1990), English *et al.* (1997) and Kirkman (1996). The non-destructive visual assessment method of Mellors (1991) for estimating seagrass standing crop *in situ* was modified for use here.

Standing crop is measured in units of dry weight organic matter per unit area (g. m^{-2}) and is correlated with shoot density and leaf area index. The visual assessment method uses a linear scale of biomass categories, which are assigned to seagrass samples in 0.25m^2 quadrats. A six-point integer reference scale of quadrats is used (1–6). The technique is summarised in Figure 9.1 and a thorough analysis of its errors and limitations is given by Mumby *et al.* (1997a).

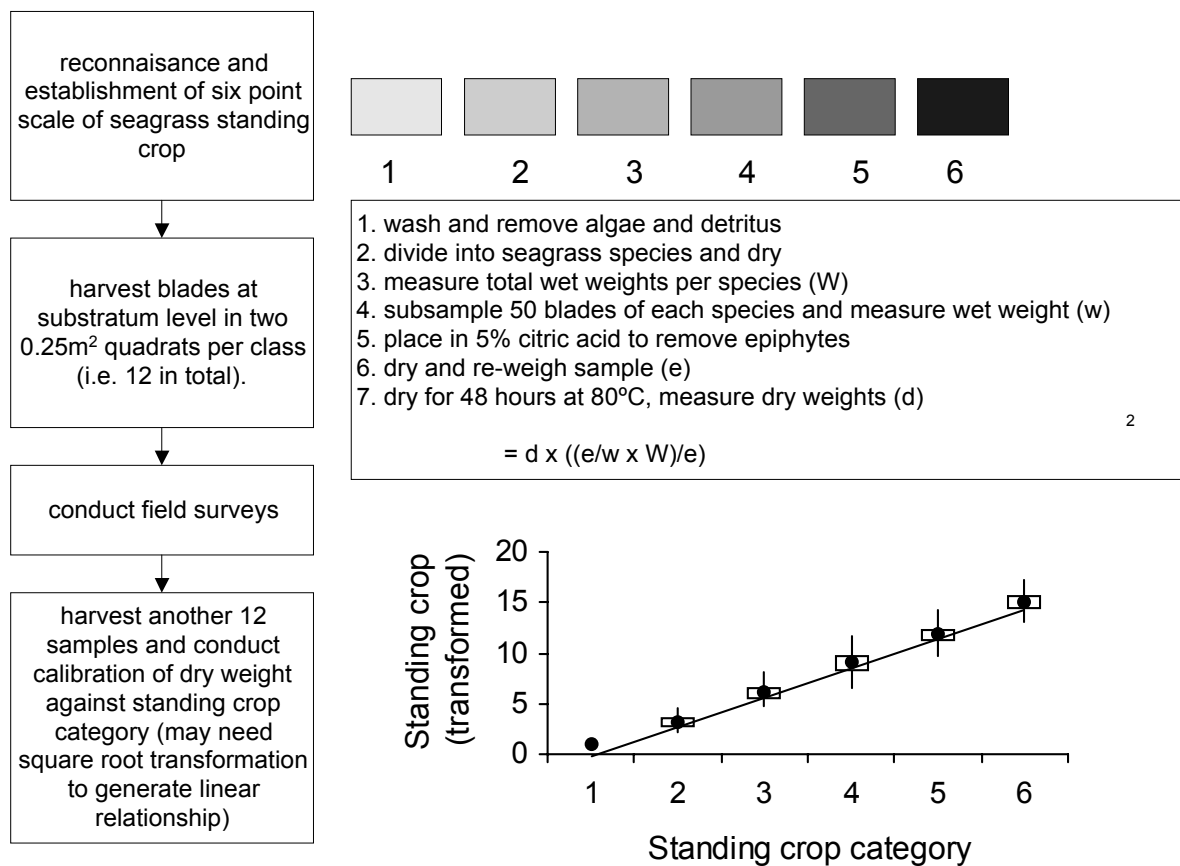



Figure 9.1. Visual assessment of seagrass standing crop

At least 30 seagrass sites should be surveyed and these should represent the entire range of standing crop in the area of interest. The size of each site will depend on the spatial resolution of the remotely-sensed imagery; larger sites are required to represent the standing crop in larger pixels. As a general guideline, we found a 10 m diameter site size to be acceptable for SPOT XS imagery. At each site, the mean standing crop of seagrass is estimated from a number of randomly placed 0.25m^2 quadrats. For medium to dense seagrass beds, a sample size of 6 quadrats is probably acceptable. However, a larger sample size should be used in patchier seagrass areas (for further discussion see Downing and Anderson, 1985).

Lesson Outline

This lesson assumes that stage 1, the collection of field data, has already been undertaken using the guidelines set out above. The first practical activity will be the second stage of preparing a map of seagrass standing crop, namely, relating field data to image data to derive a calibration graph.

Relating field data to image data: calibration of SPOT XS data into units of seagrass standing crop ($\text{g}\cdot\text{m}^{-2}$)

Activity: Launch *Bilko* and use **File, Open** to view the depth-invariant SPOT XS band of South Caicos, *SPOTXS_depth-invariant.dat*. This image is stored as floating point (32-bit) data with pixel values ranging from around -2.7736 to 6.7822. Zero is used to denote background pixels in the image; so in the **Redisplay Image** dialog box check the **Null value(s):** checkbox so that null value == 0. For the stretch, select Gaussian or Equalize from the drop-down menu and then click  to display the depth-invariant image. Note that the image has been geometrically corrected and has UTM coordinates applied.

We surveyed the standing crop of 110 seagrass sites, the positions of which were fixed using a Global Positioning System (GPS). In order to calibrate the image, the seagrass standing crop at each site needs to be related to the corresponding depth-invariant image pixel value. You will do this for just a few sites. You are provided with the UTM coordinates for five sites (Table 9.2) and the standing crops estimated at these locations during the field survey. You need to find the corresponding pixel values.

Activity: Click the point selection button and use the **Edit, Go To** command to find the pixel value at each coordinate. **Note that the status bar will display the coordinates of the centre of the pixel that overlaps the GPS position.** [The first pixel is in the extreme west of the image.] Enter the pixel values into Table 9.2 rounded to 4 decimal places. These five points can be used to generate a regression of seagrass standing crop on image data (SPOT XS depth-invariant data). Launch *Microsoft Excel* and open the workbook file *Lesson9.xls*. This file contains three worksheets: a data matrix called **Lesson**, a data matrix called **Area calculation** and a chart called **Calibration graph**. Click on *Lesson* if this is not the default sheet and enter your values into the table (the table is identical to Table 9.2, except that the coordinates are those of the centre of the pixels containing the GPS coordinates you entered; i.e. those displayed on the status bar).

Table 9.2. Relating image data to field-measured estimates of seagrass standing crop at a series of GPS coordinates. [Enter data values to **4 decimal places**, rounding as necessary.]

Site Number	Easting	Northing	Image data	Seagrass standing crop ($\text{g}\cdot\text{m}^{-2}$)
1	235077	2378832		3.79
2	242919	2392609		200.59
3	238570	2378027		109.20
4	238788	2377912		37.21
5	238669	2378027		57.00

To obtain a linear calibration graph for this image, values of seagrass standing crop must be square root transformed. This transformation has already been undertaken and the transformed values of standing crop are held in Column I labelled *y*-axis. The pixel values you entered in the table are copied automatically to the *x*-axis (Column H) and the calibration graph is constructed for you. Click on the worksheet labelled **Calibration graph** to see the plot.

Question: 9.1. What is the calibration equation derived from the 5 data points and what do the axes y and x represent? [Be as precise as possible in your answer.]

Question: 9.2. What is the coefficient of determination (r^2)? What percentage of the measured variation in seagrass standing crop is explained by the depth-invariant image pixel values?

Implementation of the calibration equation

The calibration equation calculated above was based on only five samples of field data. When we used 110 seagrass sites, we obtained the following equation, which is not dissimilar to that which you have already calculated.

$$y = 38.6 - 5.6x$$

This is the standard equation of a straight line regression where 38.6 is the intercept of the line with the y -axis (i.e. the value of y when $x = 0$), 5.6 is the magnitude of the gradient and the minus sign indicates that the slope is negative (i.e. as x gets bigger, y gets smaller).

Question: 9.3. Why do low pixel values equate to high seagrass standing crop and high pixel values equate to low seagrass standing crop?

As the y -axis variable is the square root of seagrass standing crop, the left hand side of the equation must be squared to give values in original units of seagrass standing crop (g.m^{-2}). The equation can be re-written in a slightly easier format to give:

$$\text{Seagrass standing crop} = [38.6 - (5.6 * \text{depth-invariant SPOT data})]^2$$

The calibration will be implemented at the same time as applying the land mask. Seagrass standing crop does not exceed 255 g.m^{-2} at the study site and therefore, it can be represented directly on an 8-bit image with 256 possible values for each pixel.

Activity: Open **Landmask_lesson9.gif**, select all pixels and apply an **Auto Linear** stretch. The land (and background areas) will appear black and all submerged areas will appear white. Select **Image, Connect** to link **Landmask_lesson9.gif** with **SPOTXS_depth-invariant.dat**. Ensure that the land mask is selected as image 1 in the **Selector** toolbar (**SPOTXS_depth-invariant.dat** should be set to image 2). Close the component mask and image files leaving only the connected tiled images in the viewer.

Use **File, Open** to open and view the formula document **Seagrass_step1.frm**. Note how the formula is constructed and the use of constant statements to make the formula more understandable. Make sure using the Formula document **Options!** that (i) the output image will be either the Same as @1 or 8-bit unsigned integer, and (ii) the **Use special handling for Nulls** checkbox is unchecked. Then **Copy** the formula and **Paste** it to the connected images window.

Once the new image of seagrass standing crop in g.m^{-2} has been generated, close the connected images window and select all pixels in the new image. Apply a histogram equalization contrast stretch. The land will appear black and seagrass areas will be clearly visible as grey patches in the submerged areas. Using **File, Save As**, save the image giving it the name **Seagrass_step1.gif**.

Congratulations! Each pixel has now been calibrated to represent the mean standing crop of seagrass (g.m^{-2}) in that pixel. However, such values are meaningless in habitats that are not seagrass! The next stage is to remove the non-seagrass habitats.

Masking out non-seagrass habitats

Activity: Open the seagrass mask (**Seagrass_mask.gif**) in which all non-seagrass marine areas have a pixel value of zero (both land and seagrass areas have the value 1).

The mask could be applied directly to the image of standing crop (**Seagrass_step1.gif**) but this would lose the distinction of land and sea (as both would be set to zero). Instead, you are going to produce an image that shows land boundaries, the standing crop of seagrass, and the location of all other submerged habitats. This process requires two masks, the first of which (land) has already been applied. When two masks are used (in this case land and non-seagrass habitats), two pixel values must be available to represent the masked categories. Since land already has a value of zero, this means that one value of standing crop must be sacrificed from our 1–255 g.m⁻² scale in order to assign non-seagrass habitats a pixel value. No seagrass areas in the image actually have a standing crop as high as 255 g.m⁻² so this value is free to be assigned to non-seagrass marine areas. Thus we need a formula to create an output image where land is set to zero, non-seagrass marine areas are set to 255, and pixel values in between indicate the standing crop of seagrass areas in g.m⁻² from 1–254 g.m⁻².

Activity: Use **Image, Connect** to link the **Seagrass_mask.gif** and processed file, **Seagrass_step1.gif**. Make sure that **Seagrass_step1.gif** becomes image 1 (@1 in formula) and the seagrass mask becomes image 2 (@2 in formula) using the **Selector** toolbar (this is necessary to ensure that the formula chooses images in the correct sequence). Open the formula document, **Seagrass_step2.frm** and examine how it works. If pixel values in **Seagrass_mask.gif** are 0 (indicating non-seagrass marine areas) then the output image is set to 255, otherwise (ELSE) the output image is the same as **Seagrass_step1.gif**. **Copy** the formula and **Paste** it to the connected images window. Save the output file as **Seagrass_step2.gif**, and close the connected images window and formula document.

In **Seagrass_step2.gif** dense seagrass beds should be clearly distinguishable from the land and non-seagrass habitats. Verify the designation of pixel values by clicking on land areas and non-seagrass marine areas; the pixel values should be 0 and 255 respectively. To see sparse seagrass areas more clearly you can open and apply the manual stretch **Seagrass_step2.str**.

The land and non-seagrass marine pixels will swamp any histogram of the whole image, so to see the spread of standing crop values in a seagrass bed you will need to select a subset of pixels.

Activity: Use **Edit, Go To** to select a box or block of pixels in the large seagrass bed near the north-east of the image with **top-left** UTM coordinate at position Easting: 242858, Northing: 2393518 and with a **DX:** of 943 m and **DY:** of -828 m or 828S. [*Hint:* It is important to specify the direction of block from the starting point. If the **DY:** is just entered as 828, *Bilko* will assume you mean a block running 828 m north of the position. Since the block is south of the position you need to either enter “-828” or “828S” or “828s”.] Use **File, New** to bring up a HISTOGRAM document of this pixel block (making sure that the **Apply stretches to new documents** checkbox is not checked). Then answer the following questions. [*Checkpoint:* there should be 1476 pixels in the block.]

Question: 9.4. What is the lowest value of the *seagrass* pixels and what does this represent in terms of standing crop?

Question: 9.5. What is the highest standing crop in the block and how many pixels have this standing crop?

Question: 9.6. What is the modal standing crop in the seagrass bed (based on this block sample)? How many pixels have this value?

Question: 9.7. What is the mean standing crop in the block sample? [Express answer to nearest whole gram per square metre.]

Activity: When you have answered the questions, close the histogram document.

Assigning a colour palette to seagrass standing crop

The next step is to create a colour palette to display the seagrass standing crop as five colour-coded categories corresponding to the top five classes on the visual assessment scale. The palette applies to the display image values (mapped by the Look Up Table - LUT) as opposed to the underlying data values. We want to map the underlying data values to colours and so must make sure there are no stretches in operation. Thus before proceeding further you should clear any stretches applied to **Seagrass_step2.gif**.

Activity: Clear any stretches of **Seagrass_step2.gif**, if present. Load a new colour palette using **File, New**. Select the first (top left) of the 256 cells, which represents a pixel value of zero (land). Choose an arbitrary colour for this layer but preferably an unobtrusive colour such as mid-grey.

[*Hint:* Click the upper of the palette boxes beneath the colour space and then set the **Red:**, **Green:** and **Blue:** guns to 127, then click on Update. This should set the first cell to grey. To check whether this has worked, copy the palette and paste it to the unstretched **Seagrass_step2.gif** image. All land areas (and background) should become mid-grey].

Next, select the last cell, which represents a pixel value of 255 (non-seagrass marine habitats). Set this to cyan (R=0, G=255, B=255) using the same procedure. You must now choose a colour scheme for seagrass standing crop (i.e. the remaining pixels). You can experiment, creating your own scheme and applying your palettes to the image.

For guidance, two palettes have been prepared already (these have land set to black, non-seagrass marine areas to white and seagrass to shades of green. Open the palette document **Seagrass1.pal** making sure, as you do so, that the **Apply** check-box in the **Open** dialog box is not checked.

This palette was created by selecting all seagrass boxes (i.e. boxes 1 to 254) and assigning a pale green colour to the upper palette box and a dark green colour to the lower palette box.

Activity: Try this on your palette. [*Hint:* To select the seagrass boxes, click on box 1 on your palette, and then click on box 24 while depressing <Shift>. You should see 001 254 in the status bar panels.]

The end result is a gradient of green pertaining to standing crop, with the depth of colour increasing smoothly with increasing standing crop. The limitation of this approach is that the scale is not quantified (i.e. how much seagrass = dark green?). To remedy this, a series of distinctive categories can be displayed. In the next example palette, different colours have been assigned to the top six classes of the visual assessment scale for surveying standing crop (i.e. 1–5; 6–20; 21–70; 71–130; 131–200; 201–254 g.m⁻²).

Open the palette **Seagrass2.pal** in which standing crop has been divided into 6 classes and apply this palette to the image. In this case, the colours can be related to levels of seagrass standing crop immediately by eye and you have a clear picture of the structure of the seagrass beds. Examine the large seagrass bed in the north-east of the image, zooming in to see detail. One can immediately pick out areas of dense and sparse seagrass. If you wish, experiment with improving the palette (e.g. setting non-seagrass marine habitats to cyan, or land areas to grey).

When you are finished, close the palettes and **Seagrass_step2.gif**.

Estimating the area of seagrass standing crop classes

Now that you have created a map of seagrass standing crop, the final objective is to calculate the area of seagrass in each standing crop category. In a practical situation, this might be repeated every few years to monitor changes in the coverage of particular types of seagrass bed.

Activity: Open the file **Seagrass_area.gif** which has all land and non-seagrass marine pixels set to zero but is otherwise the same as the file **Seagrass_step2.gif**. Apply the **Seagrass2.pal** palette to display the image more clearly. Ensure that all pixels are selected in the image and then create a histogram document using **File, New**. The *x*-axis displays pixel values 0–255 and the *y*-axis shows the number of pixels of each value. Because there are so many pixels with the value 0, you can't see the frequencies of most of the seagrass pixels so right-click on the histogram and select **Scale**. In the **Scale** dialog box select the **Ignore zero** check-box and click on OK.

The total size of the image is 444 x 884 pixels (see top of histogram) so there are a total of 392496 pixels in the image. Place the mouse pointer at any point on the *x*-axis and view the status bar at the bottom right-hand corner of the display. You will see four sets of numbers. The two middle numbers indicate the lowest and highest values in the range of pixel values that you have highlighted. If only one value has been selected (e.g. by clicking on a particular value on the *x*-axis) then both values will be the same. The right panel shows the number of pixels highlighted on the histogram and the left panel shows the percentage of pixels which have been highlighted. This percentage is calculated by dividing by the total number of pixels in the image. Therefore, 10% would equal $10/100 \times 392496$ pixels = 39250 to the nearest whole number.

Use the histogram to determine the **percentage of pixels** and **number of pixels** in each standing crop class. For example, the first class, which represents a standing crop from 1 to 5 g.m⁻², is displayed as pixel values 1–5. To estimate the percentage of pixels in this class, position the mouse pointer on a pixel value of 1 and drag it to the right until it reaches 5. [*Hint:* You may find it easier to use the keyboard. Press <F1> while the histogram is the active document and click on the “selecting data in a histogram” link in the Help to find out how.] The percentage displayed on the status bar will show the total percentage of pixels in this class (to the nearest 0.01%) and the right hand panel will show the total number of pixels that this represents.

Enter both values into the appropriate columns of Table 9.3 and calculate the area of each class in hectares using a calculator. Alternatively, launch *Microsoft Excel*, open the file **Lesson9.xls** and select the worksheet **Area calculation**. This sheet contains Table 9.3 and formulae to automate the area calculation. You can check your working by typing the numbers of pixels in each standing crop class into this table and comparing the area estimates to those calculated by hand. Complete Table 9.3 with the areas of each seagrass class in hectares.

Table 9.3. Calculating the area of seagrass standing crop classes around South Caicos. Total number of pixels = 392496, area of a single SPOT pixel = 23 x 23 m = 529 m², 1 hectare (ha) = 10, 000 m².

Seagrass standing crop	Pixel Range	Percent of total number of pixels	Number of pixels	Area of standing crop class (m ²)	Area of standing crop class (ha)
1 to 5	1 - 5				
6 to 20	6 - 20				
21 to 70	21 - 70				
71 to 130	71 - 130				
131 to 200	131 - 200				
201 to 254	201 - 254				
(units = g.m ⁻²)					
Land	0	50.47	198101	104795429	10479.5
Non-seagrass	255	40.45	158778	83993562	8399.4

Question: 9.8. How many pixels have a value between 201 and 254? What area in hectares (to nearest 0.1 ha) of high density (> 200 g.m⁻²) seagrass does this represent?

Question: 9.9. What is the total area of seagrass in the image in hectares (to nearest whole ha)?

Activity: When you've answered questions, close all files.

Congratulations! You've managed to produce a sophisticated map of seagrass standing crop for the Caicos Bank area around South Caicos Island by establishing an empirical model linking standing crop to pixel values in a depth-invariant image. This technique of using ground-truthing to establish an empirical relationship between image data values and some quantitative measure of an object you are interested in, has wide application.

Using a Map of Seagrass Standing Crop

A map of seagrass standing crop could be used in several ways. The simplest of these would be the provision of extra information on the status of seagrass beds in a particular area of interest. However, the maps might also be used to identify the location and extent of important fisheries habitats. For example, the juvenile conch (*Strombus gigas*) is often associated with seagrass habitats of low standing crop (Appeldoorn and Rolke, 1996). Monitoring of seagrass standing crop over time would also be possible, particularly if the remotely sensed data had a high spatial resolution. Maps showing changes in standing crop could be created and possibly related to the causes of the change (e.g. point sources of pollutants). However, if monitoring is going to be undertaken, it is important to quantify errors and assess the confidence with which remote sensing predicts seagrass standing crop. For further details of these methods, readers are referred to Mumby *et al.* (1997b). Alternatively, a simpler monitoring programme could compare the coverage of seagrass classes from, say, year to year (as outlined in this lesson).

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