

## 8: ASSESSING MANGROVE LEAF-AREA INDEX (LAI) USING CASI AIRBORNE IMAGERY

### Aim of Lesson

To learn how to assess mangrove leaf-area index (LAI) using Compact Airborne Spectrographic Imager (CASI) imagery.

### Objectives

1. To understand what field survey of the mangroves is necessary to calibrate imagery and allow Leaf-Area Index (LAI) to be estimated.
2. To learn how LAI data is derived from field measurements.
3. To prepare a Normalised Vegetation Difference Index (NDVI) of mangrove areas from the CASI imagery
4. To investigate the relationship between NDVI and LAI using UTM coordinate referenced field survey data and use this relationship to create an image of mangrove Leaf Area Index.
5. To use a palette to display mangrove LAI effectively.
6. To calculate net canopy photosynthetic production from LAI and thus obtain a crude estimate of the mangrove forest primary productivity.

### Background Information

This lesson relates to material covered in Chapters 13 and 17 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 mangrove leaf-area index (LAI) using Compact Airborne Spectrographic Imager (CASI) imagery. The mangrove was located on the island of South Caicos.

In the eastern Caribbean the limited freshwater run off of the low dry islands and the exposure of a large portion of the shoreline to intense wave action imposes severe limits on the development of mangroves. They typically occur in small stands at protected river mouths or in narrow fringes along the most sheltered coasts (Bossi and Cintron 1990). As a result most of the mangrove forests in this region are small. Nevertheless they occur in up to 50 different areas where they are particularly important for water quality control, shoreline stabilisation and as aquatic nurseries. Mangroves in the Turks and Caicos Islands are typical of this area but completely different to the large mangrove forests which occur along continental coasts and at large river deltas.

### The *Bilko for Windows* image processing software

Familiarity with *Bilko for Windows* 2.0 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. A familiarity with the *Microsoft Excel* spreadsheet package is also desirable.

## Image data

The Compact Airborne Spectrographic Imager (CASI) was mounted on a locally-owned Cessna 172N aircraft using a specially designed door with mounting brackets and streamlined cowling. An incident light sensor (ILS) was fixed to the fuselage so that simultaneous measurements of irradiance could be made. A Differential Global Positioning System (DGPS) was mounted to provide a record of the aircraft's flight path. Data were collected at a spatial resolution of 1 m<sup>2</sup> in 8 wavebands (Table 8.1) during flights over the Cockburn Harbour and Nigger Cay areas of South Caicos, Turks and Caicos Islands (21° 30' N, 71° 30' W) in July 1995. Further details are given in Clark *et al.* (1997).

**Table 8.1.** Band settings used on the CASI.

Band	Part of electromagnetic spectrum	Wavelength (nm)
1	Blue	402.5 - 421.8
2	Blue	453.4 - 469.2
3	Green	531.1 - 543.5
4	Green	571.9 - 584.3
5	Red	630.7 - 643.2
<b>6</b>	<b>Red</b>	<b>666.5 - 673.7</b>
<b>7</b>	<b>Near Infrared</b>	<b>736.6 - 752.8</b>
8	Near Infrared	776.3 - 785.4

Geometrically and radiometrically corrected Compact Airborne Spectrographic Imager (CASI) data from bands 6 (red) and 7 (near infra-red) of the area around South Caicos island are provided for the purposes of this lesson as files CASIMNG6.DAT and CASIMNG7.DAT. These files are unsigned 16-bit integer files (integers between 0 and 65535). This means that there are two bytes needed per pixel rather than the one byte needed for the Landsat TM and SPOT XS images which are only 8-bit data. Mangrove areas have to be separated from non-mangrove areas and a mask used to set water pixels and non-mangrove land pixels to zero.

## Field survey data

Three species of mangrove, the red mangrove *Rhizophora mangle*, the white mangrove *Laguncularia racemosa*, and the black mangrove *Avicennia germinans* grow with the buttonwood *Conocarpus erectus* in mixed stands along the inland margin of the islands fringing the Caicos Bank. The field survey was divided into two phases. Calibration data were collected in July 1995, accuracy data in March 1996. Species composition, maximum canopy height and tree density were recorded at all sites (Table 8.2). Species composition was visually estimated from a 5 m<sup>2</sup> plot marked by a tape measure. Tree height was measured using a 5.3 m telescopic pole. Tree density was measured by counting the number of tree trunks at breast height. When a tree forked beneath breast height (~1.3 m) each branch was recorded as a separate stem (after English *et al.*, 1994). The location of each field site was determined using a Differential Global Positioning System (DGPS) with a probable circle error of 2-5 m.

**Table 8.2.** A summary of the field survey data. Data were collected in two phases; the first in 1995 for the calibration of CASI imagery and the second in 1996 for accuracy assessment. The number of sites at which each type of data was collected during each phase are shown. Category “Other” refers to field survey data for three non-mangrove categories (sand, saline mud crust, *Salicornia* species).

Purpose of data	Number of sites	
	Calibration (1995)	Accuracy (1996)
Species composition (%)	81	121
Tree height	81	121
Tree density	81	121
Canopy transmittance	30	18
Percent canopy closure	39	20
Other	37	67

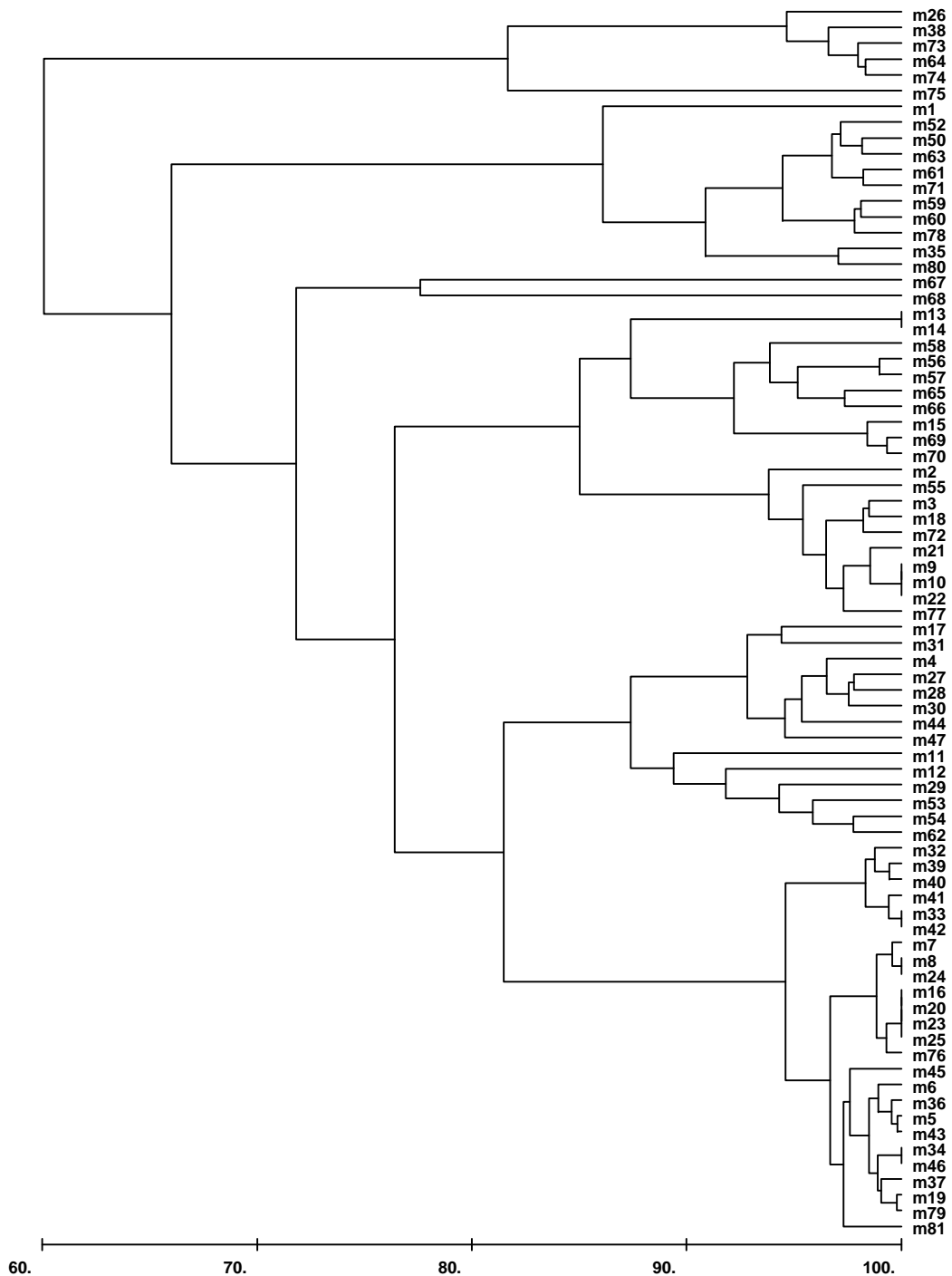
A habitat classification was developed for the mangrove areas of the Turks and Caicos using hierarchical agglomerative clustering with group-average sorting applied to the calibration data. The calibration data were 4<sup>th</sup> root transformed in order to weight the contribution of tree height and density more evenly with species composition (the range of data was an order of magnitude higher for density and height and would cluster accordingly). This identified seven classes which separated at a Bray-Curtis Similarity of 85% level of similarity (Figure 8.1). Categories were described in terms of mean species composition (percent species), mean tree height and mean tree density (Table 8.3). One category, *Laguncularia* dominated mangrove, was discarded because white mangrove was rare in this area - in both the calibration and accuracy field phases it was observed at only two locations. Three other ground cover types were recorded: (i) sand, (ii) saline mud crust, and (iii) mats of the halophytic succulents *Salicornia perennis* and *S. portulacastrum*. These nine habitat categories (six mangrove, three other) were used to direct the image classification of the CASI data and the collection of accuracy data in 1996.

Two useful ways of describing or modelling the canopy structure of a vegetated area are *leaf area index* (LAI, Box 8.1) and *percent canopy closure*. Both can be estimated from remotely sensed data, which is advantageous in areas where access is particularly difficult or when alternative methods are laborious and difficult to replicate properly over large areas.

### Leaf area index

Many methods are available to measure LAI directly and are variations of either leaf sampling or litterfall collection techniques. These methods tend to be difficult to carry out in the field, extremely labour intensive, require many replicates to account for spatial variability in the canopy and are thus costly in terms of time and money. Consequently many indirect methods of measuring LAI have been developed (see references in Nel and Wessman, 1993). Among these are techniques based on gap-fraction analysis that assume that leaf area can be calculated from the *canopy transmittance* (the fraction of direct solar radiation which penetrates the canopy). This approach to estimating LAI uses data collected from beneath the mangrove canopy and was used here.

**Figure 8.1.** Dendrogram of 78 mangrove sites using group-average clustering from Bray-Curtis similarities (bottom axis). Seven clusters which are <85% similar were identified. One consisting of sites 67 and 68 was discarded for reasons explained in the text: the other six, were used to direct the supervised classification of the CASI data and an accuracy assessment.



**Table 8.3.** Descriptions for each of the mangrove habitat categories identified in Figure 8.1. N = number of calibration sites in each category. Rhz = *Rhizophora*; Avn = *Avicennia*; Lag = *Laguncularia*; Con = *Conocarpus*.

Habitat Category Description	N	Species Composition %				Tree Height (m) mean (range)	Tree Density (m <sup>-2</sup> ) mean (range)
		Rhz	Avn	Lag	Con		
<i>Conocarpus erectus</i>	6	0	0	0	100	2.4 (1.8-4.5)	0.6 (0.5-1.0)
<i>Avicennia germinans</i>	11	0	100	0	0	2.6 (0.8-6.0)	0.6 (0.2-1.0)
Short, high density, <i>Rhizophora mangle</i>	10	100	0	0	0	1.1 (0.5-2.0)	8.0 (6.0-10.0)
Tall, low density, <i>Rhizophora mangle</i>	25	100	0	0	0	3.7 (2.0-7.0)	0.3 (0.2-0.5)
Short mixed mangrove, high density	10	62	38	0	0	1.7 (0.8-2.5)	8.1 (5.0-15.0)
Tall mixed mangrove, low density	14	56	43	0	1	3.5 (2.0-5.0)	0.6 (0.2-1.2)
<i>Laguncularia</i> dominated mangrove	2	35	5	45	0	3.8 (3.5-4.0)	2.2 (0.5-4.0)
Unclassified	3						

### Box 8.1. Leaf area index (LAI).

LAI is defined as the single-side leaf area per unit ground area, and as such is a dimensionless number. The importance of LAI stems from the relationships which have been established between it and a range of ecological processes such as rates of photosynthesis, transpiration and evapotranspiration (McNaughton and Jarvis, 1983; Pierce and Running, 1988), and net primary production (Monteith, 1972; Gholz, 1982). Measurements of LAI have been used to predict future growth and yield (Kaufmann *et al.*, 1982) and to monitor changes in canopy structure due to pollution and climate change. The ability to estimate leaf area index is therefore a valuable tool in modelling the ecological processes occurring within a forest and in predicting ecosystem responses.

Mangroves are intertidal, often grow in dense stands and have complex aerial root systems which make extensive sampling impractical with the difficulty of moving through dense mangrove stands and the general inaccessibility of many mangrove areas posing a major logistic problem. Luckily field measurements indicate that there is a linear relationship between mangrove LAI and normalised difference vegetation index (Ramsey and Jensen, 1995; 1996). NDVI can be obtained from remotely sensed data. This means that a relatively modest field survey campaign can be conducted to obtain LAI measurements in more accessible mangrove areas and these used to establish a relationship to NDVI using regression analysis. Once this relationship is known then NDVI values for the remainder of the mangrove areas can be converted to LAI.

### Measurement of canopy transmittance and calculation of LAI

LAI is a function of canopy transmittance, the fraction of direct solar radiation which penetrates the canopy. Canopy transmittance is given by the ratio  $I_c/I_o$  where  $I_c$  = light flux density beneath the canopy and  $I_o$  = light flux density outside the canopy. LAI can then be calculated, and corrected for the angle of the sun from the vertical, using the formula

$$LAI = \frac{\log_e \left( \frac{I_c}{I_o} \right)}{k} \times \cos q$$

where LAI = leaf area index,  $\theta$  = sun zenith angle in degrees (this can be calculated from time, date and position),  $k$  = canopy light extinction coefficient, which is a function of the angle and spatial arrangement of the leaves. The derivation of this formula is given in English *et al.* (1994). For each field site  $\log_e(I_c/I_o)$  was calculated for 80 pairs of simultaneous readings of  $I_c$  and  $I_o$  around the position fix and averaged. A value for  $k$  of 0.525 was chosen as being appropriate to mangrove stands.

Measurements were taken on clear sunny days between 10:00 and 14:00 hours, local time. The solar zenith angle was judged to be sufficiently close to normal (i.e. perpendicular) two hours either side of noon for directly transmitted light to dominate the radiation spectrum under the canopy. At other times the sun is too low and diffuse light predominates. Photosynthetically active radiation (PAR) was measured using two MACAM™ SD101Q-Cos  $2\pi$  PAR detectors connected to a MACAM™ Q102 radiometer. One detector was positioned vertically outside the mangrove canopy on the end of a 40 m waterproof cable and recorded  $I_o$ . The other detector recorded  $I_c$  and was connected to the radiometer by a 10 m waterproof cable. If the mangrove prop roots and trunk were not too dense to prevent a person moving around underneath the canopy this detector (which was attached to a spirit level) was hand-held. If the mangroves were too dense then the  $I_c$  detector was attached to a 5.4 m extendible pole and inserted into the mangrove stand. The spirit level was attached to the end of the pole to ensure the detector was always vertical. All recordings of  $I_c$  were taken at waist height, approximately 0.8 m above the substrate.

## Lesson Outline

### Creating a Normalized Difference Vegetation Index (NDVI) image

Since NDVI is calculated using near infra-red and red bands there were four options for calculating NDVI from the CASI data with combinations of Bands 5 to 8 (Table 8.4). The relationships between NDVI calculated from Bands 8 and 5 or from Bands 8 and 6, and values of LAI estimated from *in situ* measured canopy transmittance, were not significant. However, there were significant relationships when LAI was regressed against NDVI calculated either from Bands 7 and 6 or 7 and 5 (Table 8.4). NDVI derived from Bands 6 and 7 was deemed most appropriate for the prediction of LAI because (i) it accounts for a much higher proportion of the total variation in the dependent variable, and (ii) the accuracy with which the model predicts the dependence of LAI on NDVI is higher (the standard error of estimate is lower). This is why CASI bands 6 and 7 have been selected for this exercise.

**Activity:** Launch *Bilko for Windows* and use **File, Open** to open the 16-bit integer image files CASIMNG6.DAT and CASIMNG7.DAT which show most of the mangroves along the west coast of the southern part of South Caicos Island. Note that the CASIMNG6.DAT image in the red part of the spectrum (666.5-673.7 nm) is very dark as mangroves have low reflectances in the red part of the visible spectrum. By contrast mangroves and other vegetation reflect quite strongly in the near-infrared so that CASIMNG7.DAT (recorded in the near-IR at 736.6-752.8 nm) is comparatively bright.

Visually inspect the two images, stretching as necessary to see them clearly. Note that with a spatial resolution of around 1 m, there is quite a lot of texture visible in the mangrove canopy.

Using both images and the **Edit,GoTo** function answer the following question.

**Question:** 8.1. Is the mangrove vegetation thicker and the canopy closure greater at UTM coordinates 236520 E, 2379938 N than at 236600 E, 2379945 N, or is the reverse true? Explain the reasons behind your conclusion. [Both coordinate positions are near the bottom of the image].

**Table 8.4.** Four possible CASI red (Bands 5 and 6) and near-infrared (Bands 7 and 8) band combinations could have been used to calculate NDVI. The results of regressing NDVI, calculated from the four different combinations, on LAI are summarised below.  $R^2$  = coefficient of determination,  $p$  = probability of the F test for the model, NS = not significant at the  $p = 0.05$  level of confidence, SE = standard error of the estimate. Degrees of freedom = 1, 29 in all cases. For combinations marked \* the F-test and t-test for the slope estimate were both significant at the 0.001 level of confidence, indicating that they may be used to convert NDVI values to LAI.

NDVI equation	$R^2$	Intercept	Slope	$p$	SE
(Band 8 - Band 5)/(Band 8 + Band 5)	0.22	0.19	0.05	NS	1.93
(Band 8 - Band 6)/(Band 8 + Band 6)	0.12	3.68	2.29	NS	2.18
<b>(Band 7 - Band 6)/(Band 7 + Band 6)*</b>	<b>0.77</b>	<b>0.31</b>	<b>9.76</b>	<b>&lt;0.001</b>	<b>0.99</b>
(Band 7 - Band 5)/(Band 7 + Band 5)*	0.43	1.81	5.71	<0.001	1.69

The next step is to calculate a Normalised Difference Vegetation Index image (Box 8.2) from the CASI bands 6 and 8. In a real life situation you would check all possible band-pair combinations and see which was best for predicting LAI. Here we will just work with the band pair which we found to give best results.

### Box 8.2 The use of vegetation indices in the remote sensing of mangroves

Vegetation indices are complex ratios involving mathematical transformations of spectral bands. As such, vegetation indices transform the information from two bands or more into a single index. For example, the normalised difference vegetation index or NDVI is a common vegetation index calculated from red and infra-red bands:

$$\text{NDVI} = \frac{\text{infrared} - \text{red}}{\text{infrared} + \text{red}}$$

*Activity:* **Connect** the CASIMNG6.DAT and CASIMNG7.DAT images and use the connect toolbar to make sure CASIMNG7.DAT (the infra-red image) is the first image (@1 in a Formula document) whilst CASIMNG6.DAT is the second (@2). Rather than using the standard NDVI option, we will write a simple Formula document to calculate NDVI in order to understand better what is being calculated. This should be of the form of the equation in Box 8.2. Thus our Formula document equation should look something like this:

$$(@1 - @2) / (@1 + @2) ;$$

Prepare a Formula document to carry out the NDVI. Since the resultant image will display NDVI on a scale of -1 to +1, use the Formula document **Options!** to select the output image as **Float (32 bit)** and then **Copy** and **Paste** the formula to the connected images.

To establish a regression relationship that allows LAI to be predicted from NDVI, for 30 ground-truthed points where Leaf Area Index (LAI) was measured in the field, the corresponding NDVI is noted. This is done by averaging the NDVI of the nearest nine pixels to the UTM coordinates of the ground-truthing site. The average NDVI is considered to correspond to the recorded LAI. Thus each NDVI value is averaged across a 3 x 3.3 m square on the ground-surface. This allows for some error in the UTM coordinates obtained from the Differential GPS (probable circle error of 2-5 m) during the ground-truthing surveys.

The results of this calibration exercise are summarised in Table 8.6 below but the calculation of average NDVI for two sites has been left for you to do. Site 72 has short sparse mangrove and thus a relatively low LAI, whilst site 79 is on the edge of a reasonably dense stand of mangrove and has a much higher LAI. Both sites are towards the south-east of the image.

*Activity:* Save the NDVI image as MANGNDVI.DAT. To display the UTM coordinates of the cursor on the status bar use the **View, Coords** function. Scroll to the bottom of the image which is where the two sites are located. You now need to use **Edit, GoTo** to locate site 72 on the image and once you have done this you need to read off (from the status bar) the data values at the coordinates (central pixel) and the eight surrounding pixels and enter these in Table 8.5 below. The central pixel at site 72 should have the value 0.1967 (to 4 decimal places). [*Hint:* Hold down the CTRL key and use the arrow keys to move one pixel at a time].

**IMPORTANT.** The **Edit, GoTo** function tries to get you to the nearest pixel to the coordinates entered; sometimes the coordinates you enter may be half way between two pixels. Such is the case for the central pixel of Site 79. Note that the **Edit, GoTo** puts you on 236693, 2380129 so you need to move down one pixel to get to the central pixel which should have the value 0.6065. Use the <CTRL>+<DOWN> arrow key.



**Table 8.5.** Calculating average NDVI for two ground-truthing sites.  
 [Enter values to **4 decimal places**].

<b>Site 72</b>	<b>Site 79</b>
<b>Central pixel: X: 236700, Y: 2379827</b>	<b>Central pixel: X: 236693, Y: 2380128</b>

Use a calculator to work out the average NDVI for each site and enter the value (to **four decimal places**) in Table 8.6 (see next page). You now have a complete set of data to calculate the regression relationship between LAI and NDVI.

*Question:* 8.2. What are the average NDVIs at site 72 and 79 (to **two decimal places**)?

**Table 8.6.** Calibration data for regression of LAI on NDVI (calculated for CASI bands 7 and 6).

Site	UTM coordinates		NDVI	Mangrove
	Easting	Northing	CASI 7/6	LAI
31	237118	2378993	0.70	6.61
33	237105	2378990	0.75	7.32
34	237094	2378986	0.81	8.79
36	237114	2379026	0.63	6.62
37	237103	2379022	0.78	7.83
39	237087	2379071	0.79	6.17
40	237092	2379075	0.73	6.87
43	237115	2379080	0.69	6.96
44	237070	2379373	0.47	2.53
47	237038	2379376	0.75	6.61
52	237026	2379456	0.28	2.52
53	237005	2379491	0.64	5.04
54	236989	2379500	0.63	5.35
56	237008	2379445	0.61	4.76
59	237020	2379567	0.29	2.33
61	236997	2379540	0.42	4.34
62	236978	2379547	0.47	4.96
64	236932	2379588	0.24	1.93
65	236890	2379549	0.47	5.82
66	236872	2379554	0.42	3.74
67	236759	2379649	0.49	6.58
68	236731	2379664	0.43	3.89
71	236718	2379777	0.59	5.59
<b>72</b>	<b>236700</b>	<b>2379827</b>		<b>1.64</b>
73	236723	2379825	0.29	2.33
75	236668	2379932	0.19	1.99
78	236579	2380039	0.35	2.03
<b>79</b>	<b>236693</b>	<b>2380128</b>		<b>5.83</b>
80	236703	2380141	0.61	2.95
81	236728	2380128	0.47	5.05

### Regression of LAI on NDVI

You now need to carry out the regression of Leaf Area Index on NDVI to allow you to map LAI from the CASI imagery. Luckily there is a simple linear relationship between LAI and NDVI defined by the regression equation:

$$\text{LAI} = \text{intercept} + \text{slope} \times \text{NDVI}$$

*Activity:* Open the *Excel* spreadsheet file MANGNDVI.XLS. Insert your NDVI values for sites 72 and 79. Examine the graph of LAI against NDVI and note that LAI is roughly ten times NDVI. Use **Tools, Data Analysis** to regress the column of LAI values (Input Y Range:) against the column of NDVI/6 values (Input X Range:). For the Output Range: just select a cell below the calibration dataset. Note that the regression is very significant, i.e. that NDVI is a good predictor of Leaf Area Index. You only need two pieces of information from the output of the regression analysis, the slope of the regression line and where it intercepts the y-axis. The **intercept** (which should be a small negative number) is labelled as such, whilst the value for the **slope** of the line is labelled “X variable” in the regression output.

*Question:* 8.3. What is the intercept and slope of the regression of LAI on NDVI (to 4 decimal places)?

Knowing the relationship between NDVI on the image and LAI measured in the field we can now make an 8-bit (byte) image of Leaf Area Index by applying a Formula document to convert NDVI to LAI. From the graph of LAI against NDVI we know that the maximum LAI we will find is about 10. To spread our LAI measure over more of the display scale (0-255) whilst making it easy to convert pixel values to LAI we can multiply by 10. This will mean that LAI values up to 2 will map to pixel values between 1 and 20, and so on (see table to right). Thus a pixel value of 56 in the output image will indicate an LAI of 5.6.

LAI range	Pixel values
< 2	1-20
2-4	21-40
4-6	41-60
6-8	61-80
> 8	81-100

The Formula document will thus need to be something like this:

$$(\text{intercept} + \text{slope} * @x) * 10 ;$$

where you substitute the values you obtained in the regression analysis for the *intercept* and *slope* and @x is the NDVI image.

*Activity:* You need to have a connected images window open to apply a Formula document so we need a file to connect the MANGNDVI.DAT image to. In the **Image, Connect** dialog box make sure that **Blanks:** is set to 1 and then click on OK. Use the connect toolbar to make sure that MANGNDVI.DAT is the first image (@1) whilst the blank image is @2.

Use **File, New** to open a new Formula document and enter a formula (see above) to carry out the conversion of NDVI to LAI (use constant statements as appropriate to set up input values and make the formula easy to understand). Use the Formula document **Options!** to make sure the output image is **Byte (8 bits)** and then **Copy** the formula and **Paste** it to the connected images. The resultant image will be dark because the highest pixel value is only 100. To see the distribution of mangrove with different levels of LAI, open the Palette document LAI.PAL whilst the LAI image is the active document. The palette will be automatically applied to the image [assuming **Apply** is checked in the **File, Open** dialog box] and displays each of the five ranges of LAI in a different shade of green to green-brown. Note that mangrove areas with a Leaf Area Index greater than 8 are very rare.

*Check:* Note the value of the pixel at x, y (column, row) coordinate 324, 1167 in the MANGNDVI.DAT image. It should be 0.8333. Use a calculator to work out what its LAI value should be using your equation. It should be 7.8 and thus the pixel value at 324, 1167 on the LAI image should be 78. If it isn't something has gone wrong.

The next stage is to assess the status of the mangroves in the image area. Firstly, you will calculate what proportion of the image area consists of mangrove of each LAI class. The easiest way to do this is to use *Bilko*'s histogram capabilities.

*Activity:* Select all the image and use **File, New** to bring up a histogram showing the frequencies of pixel values. [*Hint:* you will probably need to set Ignore zero in order to see the histogram properly]. Position the mouse pointer at 100 on the x-axis and holding down the left mouse button drag it until it is over 81. The status bar should indicate that 0.05% of the pixels are highlighted. Note the percentage highlighted in Table 8.7 below. Repeat

for 80 to 61, 60 to 41, 40 to 21, 20 to 1 and finally find out what percentage of pixels are non-mangrove (i.e. set to zero). Make sure the percentages add up to 100.

*Question:* 8.4. What percentage of the image area is mangrove?

From the histogram header one can see that the image is 500 pixels wide and 1325 pixels long. Knowing that each pixel is 1.0 m wide and 1.1 m long, calculate the area of the whole image in hectares (1 ha = 100 x 100 m = 10,000 m<sup>2</sup>). Complete Table 8.7 with all values recorded to one decimal place, then answer the questions below.

*Question:* 8.5. What is the area of the whole image in hectares (to the nearest hectare)?

8.6. What is the total area of mangrove in hectares (to the nearest hectare)?

8.7. How many hectares of mangrove have an LAI > 6 and what proportion of the total mangrove area does this represent?

**Table 8.7.** Interrogating the image regarding the status of the mangroves.

LAI range	Pixel values	% pixels (= % area)	Area (hectares)
Sea/non-mangrove	0		
< 2	1-20		
2-4	21-40		
4-6	41-60		
6-8	61-80		
> 8	81-100	0.05	
Total area of mangrove			
Total area of image			

### Estimation of net canopy photosynthetic production (P<sub>N</sub>)

The approximate net photosynthetic production of the whole mangrove canopy per m<sup>2</sup> of ground area over a day can be described by the following equation:

$$P_N = A \times d \times LAI$$

where A = average rate of photosynthesis (gC m<sup>-2</sup> leaf area hr<sup>-1</sup>) for all leaves in the canopy, d = daylength (hr), and LAI is the leaf area index already estimated for each pixel (English *et al.* 1994). For mangroves in high soil salinities in the dry season a reasonable estimate for A = 0.216 gC m<sup>-2</sup> hr<sup>-1</sup> and daylength in the Turks and Caicos is on average about 12 hours. Using this relationship we can make a rough estimate of the net photosynthetic production in each LAI class, indeed, if one had good field data on the average rate of photosynthesis (A) one might in theory make an image where pixel values related to P<sub>N</sub>. For the purpose of this lesson we are just going to make a crude estimate of the number of tonnes of carbon fixed per hectare each year (tC ha<sup>-1</sup> year<sup>-1</sup>) by the mangrove area with an LAI of 6-8.

*Activity:* Let the average LAI of the mangrove area with an LAI of 6-8 be 7. Using the equation estimate the daily net photosynthetic production per m<sup>2</sup> (in gC m<sup>-2</sup>). Convert this to tC ha<sup>-1</sup> year<sup>-1</sup>. Use your value for the area occupied by mangrove with LAI 6-8 to estimate how many tonnes of carbon are fixed per year by these mangroves.

- Question:* 8.8. What do you estimate the daily net photosynthetic production of the mangroves with LAI 6-8 in  $\text{gC m}^{-2}$ ? What is this as an annual production in units of  $\text{tC ha}^{-1} \text{ year}^{-1}$ ? [Show your working].
- 8.9 How many tonnes of carbon are fixed per year by these mangroves (LAI 6-8) in the area of the image?

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### Answers to Questions

- 8.1. The mangrove vegetation is thicker and has greater canopy closure at UTM coordinates 236520 E, 2379938 N than at 236600 E, 2379945 N. In the near infra-red band the image is much brighter at the former position (reflectance 5287 as opposed to 2290), whilst in the red waveband it is darker (reflectance 462 as opposed to 865). Vegetation reflects in the near-IR and absorbs in the red.
- 8.2. The average NDVIs at site 72 is 0.2586 (i.e. 0.26). The average NDVI at site 79 is 0.5710 (i.e. 0.57).

**Table 8.5.** Calculating the average NDVI for two ground-truthing sites. Sum the individual pixel values and divided by 9 to get average NDVI in original image units for Table 8.6.

Site 72			Site 79		
Central pixel: X: 236700, Y: 2379827			Central pixel: X: 236693, Y: 2380128		
0.3859	0.4196	0.2701	0.5803	0.6553	0.6553
0.2974	0.1967	0.1584	0.5118	0.6065	0.6723
0.1840	0.1967	0.2190	0.3783	0.5077	0.5718

- 8.3. The intercept of the regression line with the y-axis is -0.3123. The slope of the regression line is 9.7566.
- 8.4. The percentage of the image area that is occupied by mangroves is 55.3%.
- 8.5. The area of the whole image is approximately 73 ha.
- 8.6. The total area of mangrove habitats is approximately 41 ha.
- 8.7. 9.64 ha of mangrove have an LAI of > 6 (and are thus dense mangroves). This represents about 25% [23.9%] of the total area of mangroves.

**Table 8.7.** The status of the mangroves in the image.

LAI range	Pixel values	% pixels (= % area)	Area (hectares)
Sea/non-mangrove	0	44.69	32.6
< 2	1-20	8.60	6.3
2-4	21-40	8.79	6.4
4-6	41-60	24.72	18.0
6-8	61-80	13.15	9.6
> 8	81-100	0.05	0.04
Total area of mangrove		55.31	40.3
Total area of image		100.00	72.9

- 8.8.  $A = 0.216 \text{ gC m}^{-2} \text{ hr}^{-1}$ ,  $d = 12 \text{ hours}$ ,  $\text{LAI} = 7$ . So the daily net photosynthetic production  $P_N = 0.216 \times 12 \times 7 = 18.144 \text{ g C m}^{-2}$ . To convert to units of  $\text{tC ha}^{-1} \text{ year}^{-1}$  you need to multiply by 10,000 ( $\text{m}^{-2}$  to  $\text{ha}^{-1}$ ), multiply by 365 (days to years) and divide by 1,000,000 (grams to tonnes). Thus the annual net photosynthetic production of this type of mangrove is about  $66.2 \text{ tC ha}^{-1} \text{ year}^{-1}$ .
- 8.9. The 9.6 ha of mangrove with an LAI of 6-8 would thus fix  $9.6 \times 66.2 =$  approximately 635 tonnes C annually.

### Example Formula documents:

1) To calculate NDVI:

```
# Formula to calculate NDVI [Lesson 8]
```

```
# @1 = near infra-red image (in this case CASIMNG7.DAT)
```

```
# @2 = red image (in this case CASIMNG6.DAT)
```

```
# The output image needs to be Float (32 bit)
```

```
CONST Infrared = @1 ;
```

```
CONST Red = @2 ;
```

```
(Infrared - Red) / (Infrared + Red) ;
```

2) To calculate LAI:

```
# Formula to calculate LAI from NDVI for CASI mangrove image [Lesson 8]
```

```
# LAI has been regressed against NDVI and the intercept and slope of the linear
```

```
# relationship have been found. These will be set up as constants.
```

```
# The formula assumes MANGNDVI.DAT is @1 and the blank image is @2.
```

```
# The output image is an 8-bit GIF file where pixel value = LAI * 10.
```

```
CONST intercept = -0.3123 ;
```

```
CONST slope = 9.7566 ;
```

```
CONST ScaleFactor = 10 ;
```

```
( intercept + slope * @1 ) * ScaleFactor ;
```

***Photographic credits:***

A number of photographic images are made available in this module as .GIF files. Photographs were provided by Alasdair Edwards, Edmund Green, Peter Mumby and Jonathan Ridley. Those provided by Jonathan Ridley (Coral Cay Conservation) have image names prefixed with “CCC”.

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