

## 1: VISUAL INTERPRETATION OF IMAGES WITH THE HELP OF COLOUR COMPOSITES: GETTING TO KNOW THE STUDY AREA

### Aim of Lesson

To learn how to interpret satellite and airborne digital imagery visually, relate features revealed on images to features on the Earth's surface, and understand how images can help in planning field survey.

### Objectives

1. To become proficient in preparing colour composite images of both satellite and airborne imagery for visual interpretation.
2. To learn to use field reconnaissance data to assist in visually interpreting images.
3. To understand how satellite and aerial imagery may be used to aid planning of field surveys.
4. To introduce you to the problem of differential attenuation of light of different wavelengths through the water column.

### Overview of Lesson

A simple visual interpretation of remotely-sensed imagery can often reveal considerable detail on the nature and distribution of habitats in the area of interest. Visual interpretation is the identification of features based on their colour, tone, texture and context within the imagery. To visually interpret digital data such as satellite images, individual spectral bands must be displayed simultaneously in the form of a colour composite. For example, Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) and IKONOS-2 bands 1, 2 and 3 (Appendix 1.1 and 1.3) broadly represent the blue, green and red parts of the electro-magnetic spectrum (EMS). When these bands are fed through the corresponding blue, green and red “colour guns” of a computer monitor, the resulting image resembles what our eyes would see from the sensor's vantage point. We thus have an intuitive understanding of the colours presented and can usually make an informed interpretation of the scene (e.g. dark blue probably represents deep water). Such images are called *true colour composites* (TCC).

This lesson begins by describing how to make a colour composite image from the spectral bands of SPOT XS (Appendix 1.2). SPOT XS does not have a spectral band in the blue part of the EMS, so the composite is biased towards longer (red) wavelengths and is known as a *false colour composite* (FCC). However, false colours can still be related to habitats of interest and photographs are provided to relate the FCC to some of the mangrove habitats present in the area represented by the image. The other marine habitats described in this module are introduced by visually interpreting an image of Cockburn Harbour, South Caicos that was acquired using an airborne multispectral digital sensor called the Compact Airborne Spectrographic Imager (CASI: see Appendix 1.4).

Fieldwork is an essential part of any remote sensing study and the lesson ends with a discussion of how visual interpretation can aid the planning of field surveys.

### Background Information

Chapters 4 and 10 of the *Remote Sensing Handbook for Tropical Coastal Management* discuss the use of visual interpretation for planning field surveys and habitat mapping respectively, and you are recommended to consult this book or similar texts for further details.

## The *Bilko 3* image processing software

Familiarity with *Bilko 3* is required to carry out this lesson. Most of the lesson is confined to locating coordinates on images, interpreting images visually and matching areas of habitat on images to photographs taken during field survey. Tutorials 2 and 3 in the *Introduction to using the Bilko 3 image processing software* are particularly relevant and provide a good grounding for this lesson.

### Image data

Most of the images used in this module are of the Turks and Caicos Islands, to the south-east of the Bahamas. The first image was acquired by a multispectral sensor (XS), which was mounted on the first three SPOT satellites. It was acquired on the 27<sup>th</sup> March 1995 at 15:28 hours Universal Time (i.e. at approximately 10:30 local time in the Turks and Caicos Islands). The full extent of this SPOT image is presented in Figure 1.1 but only a subset of the scene, centred on the South Caicos area, is provided here (see Figure 1.2 for location). SPOT XS has three spectral bands which are represented by the files **SPOTXS\_SCaicos#01.gif** (green waveband), **SPOTXS\_SCaicos#02.gif** (red waveband), and **SPOTXS\_SCaicos#03.gif** (infra-red waveband). Following geometric correction and resampling, each pixel on this image covers 23 m x 23 m on the ground/sea (not 20 m x 20 m as you might expect).

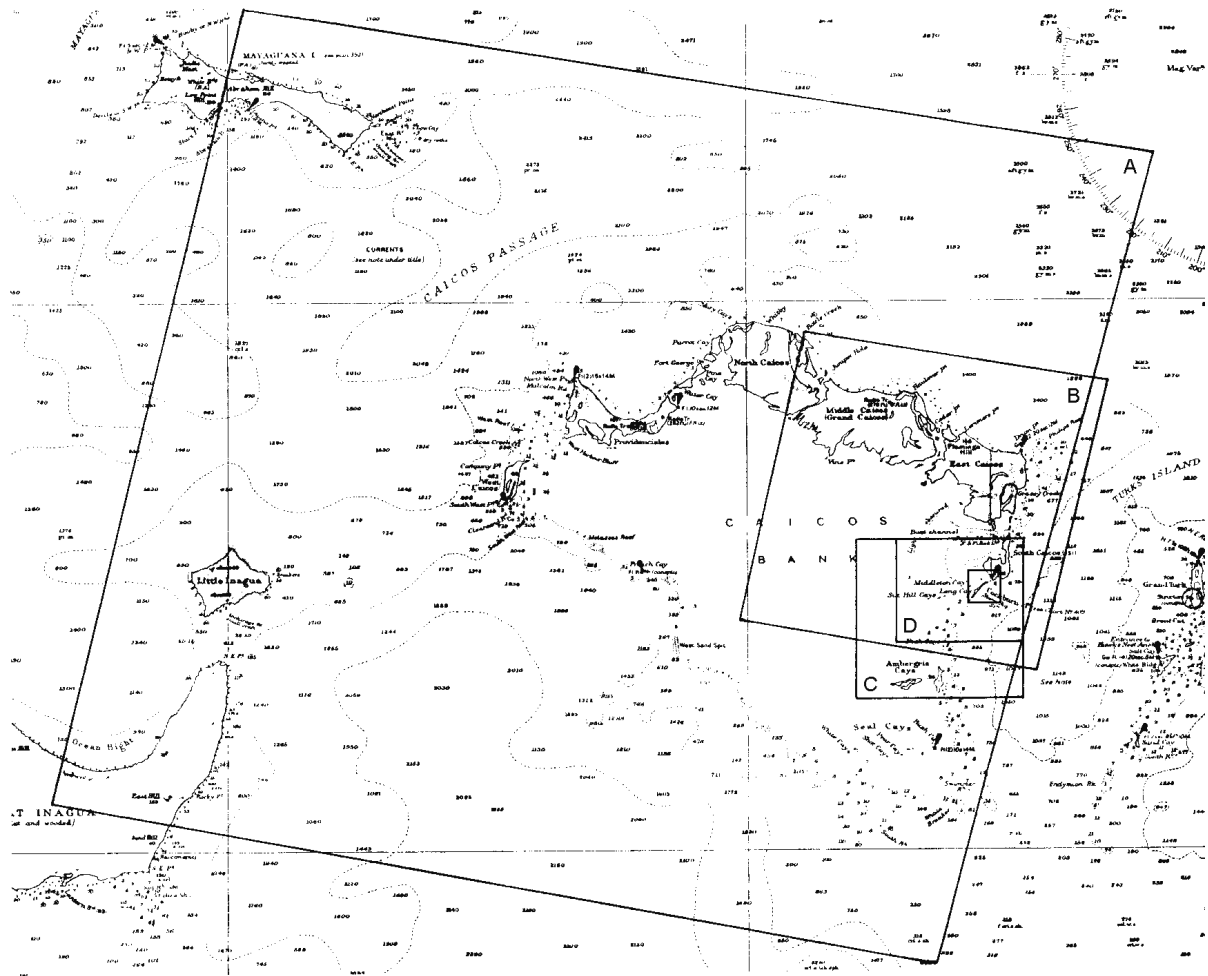
The second image (**CASI\_Cockburn\_Harbour#05+#03+#01.set**) is a colour composite of CASI data acquired for Cockburn Harbour (see inset of Figure 1.2). The CASI was mounted on a locally-owned Cessna 172N aircraft using a specially designed door with mounting brackets and streamlined cowling. An incident 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 1.1) during flights over the Cockburn Harbour area 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). Images were geometrically corrected using the UTM (zone 19) projection, Clarke 1866 spheroid and NAD27 (Bahamas) datum.

Table 1.1. 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
6	Red	666.5 - 673.7
7	Near Infra-red	736.6 - 752.8
8	Near Infra-red	776.3 - 785.4

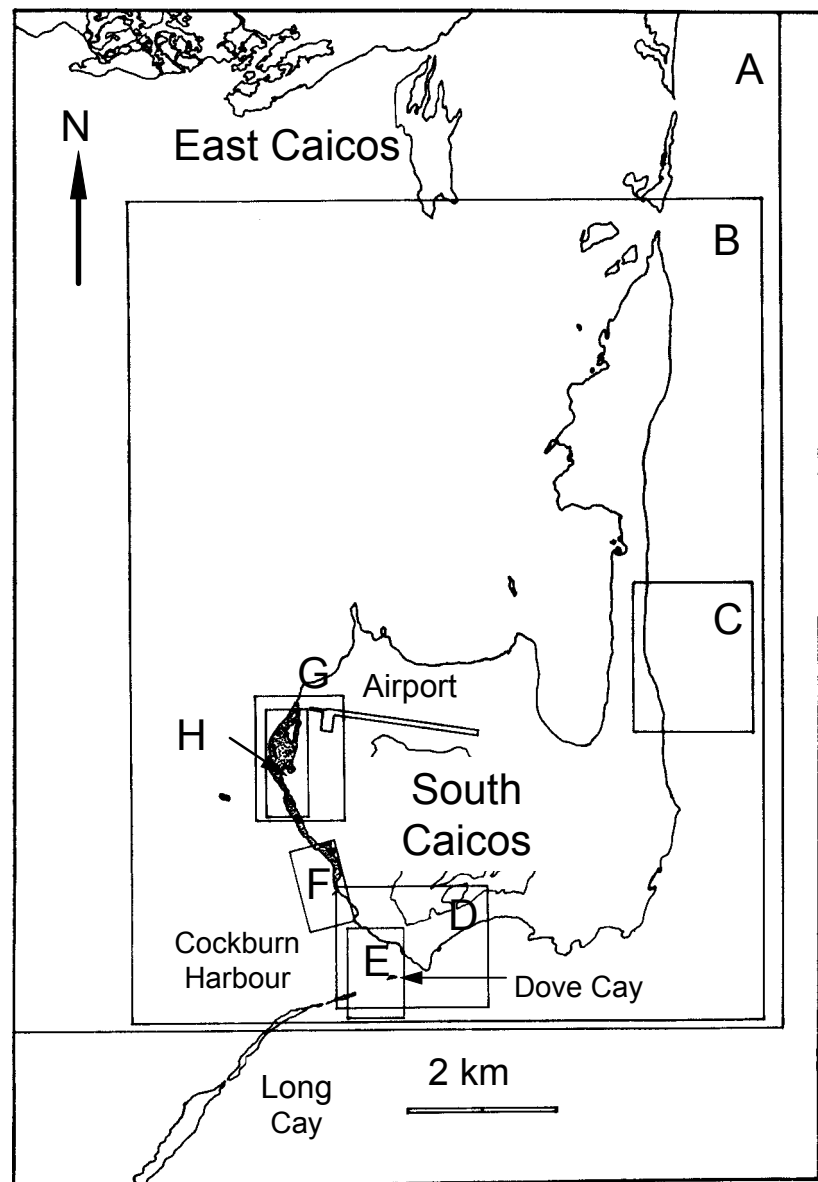
The CASI image displayed here was acquired at approximately 10 a.m. local time on 16 July 1995. For the purposes of this lesson, a colour composite image has been created and saved as a *Bilko* set comprising bands 1, 3 and 5 (Table 1.1). When the set is opened the 3 constituent bands (**CASI\_Cockburn\_Harbour#01.dat**, **CASI\_Cockburn\_Harbour#03.dat** and **CASI\_Cockburn\_Harbour#05.dat**) are opened and displayed through the blue, green and red guns respectively.

**Figure 1.1.** Location of the Landsat and SPOT scenes from which sub-scenes were taken and areas of two of the larger Landsat sub-scenes. Showing position on part of UK Hydrographic Office Admiralty Chart 1266 of the south-eastern Bahama Islands.



- A. Approximate area covered by whole Landsat TM and MSS scenes (roughly 185 km x 185 km) from which sub-scenes were taken.
- B. Area covered by whole SPOT XS and Pan scenes (60 km x 60 km) from which sub-scenes (see Figure 1.2) were taken. Note that one Landsat scene contains about 9 SPOT scenes.
- C. Approximate area covered by Landsat MSS sub-scenes used in Lesson 2 (**LandsatMSS\_Caicos#01.gif** – **LandsatMSS\_Caicos#03.gif**) and Landsat TM sub-scene used in Lesson 6 on mapping bathymetry (**LandsatTM\_bathymetric#01.gif** – **LandsatTM\_bathymetric#04.gif**).
- D. Location of Landsat TM sub-scenes used in Lesson 4 on radiometric correction. The small square within area D shows approximate location of IKONOS sub-scenes used in Lesson 2 to show appearance of 4 m multispectral and 1 m panchromatic satellite imagery.

**Figure 1.2.** South Caicos area to show locations of principal images used. Mangrove areas on the west coast of South Caicos are stippled.

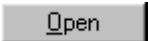


- A. Boundaries of SPOT XS sub-scenes used in Lessons 1 and 2 (*SPOTXS\_SCaicos#01.gif – SPOTXS\_SCaicos#03.gif*).
- B. Boundaries of SPOT Pan sub-scene used in Lesson 2 (*SPOTXP\_SCaicos.gif*).
- C. Location of aerial photographic sub-scene *AP\_east\_SCaicos.gif* used in Lesson 2.
- D. Location of aerial photographic sub-scene *AP\_south\_SCaicos.gif* used in Lesson 2.
- E. Location of CASI (Compact Airborne Spectrographic Imager) images used in Lessons 1 and 2 (*CASI\_Cockburn\_Harbour#05+#03+#01.set*) and in Lesson 7 on water column correction (*Casi\_16-bit\_SCaicos#02.dat – Casi\_16-bit\_SCaicos#05.dat*).
- F. Approximate location of the CASI colour composite image of mangroves used in Lesson 2 (*CASI\_mangrove#07+#05+#03.set*).
- G. Location of aerial photographic subscene *AP\_mangrove\_SCaicos.gif* used in Lesson 2.
- H. Location of CASI images used in Lesson 10 on assessing mangrove leaf area index (*Casi\_mangrove#06.dat – Casi\_mangrove#07.dat*).

## Lesson Outline

### Creation of a false colour composite from SPOT XS data

Your first task is to make a colour composite image of a geometrically corrected three-band SPOT sub scene of the island of South Caicos.

*Activity:* Launch *Bilko*. In the **File, Open** dialog box deselect **Extract** and **Minimize** (if these are checked). Then select **SPOTXS\_SCaicos#01.gif** from the list of image files with the mouse pointer and with the <Ctrl> key held down select **SPOTXS\_SCaicos#02.gif** and **SPOTXS\_SCaicos#03.gif** also, then click on . This should open all three SPOT XS images at once.

*Question:* 1.1. How many kilometres wide and long is the SPOT sub scene [*Hint: interrogate the **Edit, Go To** dialog box after selecting the whole of an image in one band*]?

*Activity:* Connect the three images using the **Image, Connect** function (highlight each with the cursor whilst depressing the <Ctrl> key, or select first and last images whilst depressing the <Shift> key), leaving the **Stacked** checkbox unchecked. Click on the **Selector** toolbar buttons so that the third connected image (**SPOTXS\_SCaicos#03.gif** – XS near-infra-red band) is designated image 1, the **SPOTXS\_SCaicos#02.gif** (XS red band) as image 2, and **SPOTXS\_SCaicos#01.gif** (XS green band) as image 3. Now select the **Image, Composite** function to make a false colour composite.

Remember that the image you designate 1 (@1) is displayed using the red gun of the computer monitor, image 2 using the green gun, and image 3 using the blue gun – hence the term RGB monitor.

*Activity:* Select the whole of the colour composite image using **Edit, Select All** or <Ctrl>+A and experiment with different stretches (**AutoLinear**, **Equalize** and **Gaussian**) to display the colour composite to full advantage. Choose the stretch that gives the greatest visual contrast. [We found the automatic linear stretch to be best.] Keep the colour composite image in the viewer but select and close all other images individually. Do not save any changes to image files.

*Question:* 1.2. What principal colour is the land in the colour composite? Why is this? Why is the deep sea dark blue and shallow water cyan in colour?

*Question:* 1.3. Between which approximate column and row ( $x, y$ ) coordinates does the runway, including cleared areas at either end (see Figure 1.2 for location) on South Caicos Island run? Roughly how many kilometres long (to the nearest 0.1 km) is the runway?

### Visual interpretation of SPOT XS Imagery of South Caicos

#### Part 1: Identification of mangrove habitats of South Caicos

You are now going to follow a transect across the mangrove fringing the coast starting at the water's edge. Mangrove forests often exhibit well-defined patterns of species zonation from the water's edge to the higher and drier land further within the forest. To simplify finding locations on the image we will use column and row coordinates rather than the Universal Transverse Mercator (UTM) Eastings and Northings to which the image is georeferenced.

*Activity:* If Eastings and Northings are displayed on the Status Bar then switch these off using **View, Coords**. Use the **Edit, Go To** command to place the cursor at  $x, y$  coordinates 179, 475 (make sure that the **Selection Type:** is set to Point Selection). If you cannot see the winking cursor, scroll down the image [*hint: use mouse wheel, if present*]. Position the mouse pointer over the cross and double-click. The image will zoom in. Double-click again. (*Note: you can zoom out by depressing <Ctrl> whilst double-*

clicking)<sup>1</sup>. You should note a red coloured (high infra-red reflectance) belt along the west coast of the island, which corresponds to a mangrove stand. A northward-facing colour aerial photograph was taken at the position of the cursor. To view the photograph, use **File, Open** and select **Mangrove\_aerial.bmp**. The dark green band of mangrove is clearly visible along the waters edge. Note also the west end of the runway and channel just off the coast (compare positions on aerial photograph and SPOT image). Close the aerial photograph file.

Click on the false colour composite image and use the **Edit, Go To** command to place the cursor at each of the column (X:) and row (Y:) positions in Table 1.2. At each position, open the corresponding photograph which was taken during field work (*Hint*: Close each photograph before moving on to the next).

**Table 1.2.** Visual interpretation of SPOT XS data to examine mangrove zonation

Coordinates		Photograph	Notes
X:	Y:	file name	
184	472	<b>Mangrove_red_short.bmp</b>	Fringing stand of short Red mangrove ( <i>Rhizophora mangle</i> ), which is usually found near the water's edge. This mangrove stand is continually advancing seaward making this a dynamic area of mangrove proliferation.
188	472	<b>Mangrove_red_tall.bmp</b>	A forest of tall Red mangrove ( <i>Rhizophora mangle</i> ), which can reach 7 m in height.
190	472	<b>Mangrove_black.bmp</b>	An area of tall Black mangrove ( <i>Avicennia germinans</i> ), which is usually found set back from the water's edge in drier environments.
194	472	<b>Mangrove_white.bmp</b>	The short, scrubby White mangrove ( <i>Laguncularia racemosa</i> ), which is found on higher ground where it is often interspersed with non-mangrove vegetation.

## Part 2: Identification of some marine habitats in Cockburn Harbour

The second part of this section will focus on the main submerged habitats of Cockburn Harbour which lies to the south-east of the area you have just viewed for mangrove habitats (see Figure 1.2).

*Activity:* Use the **Edit, Go To** command to place the cursor at coordinates 205, 510. A colour aerial photograph was taken in a south-eastward direction at this point. To view the photograph, use **File, Open** to select the file **Cockburn\_harbour.bmp**. The coast of Cockburn Harbour is visible and the long island opposite is Long Cay whose northernmost point lies at position 222, 578 in the SPOT image. The foreground of the photograph shows a mosaic of seagrass beds and sand patches. Close the aerial photograph.

Using the **Edit, Go To** command, move the cursor to position 215, 536 in the SPOT composite image. Position the mouse pointer over the cursor and double-click on the image to zoom in further (or depress the <Ctrl> key and rotate the mouse-wheel). The image looks very dark in this area because the habitat there is dense seagrass, which has a generally low albedo. To see how this seagrass looks underwater, open the file **Seagrass\_dense.bmp**.

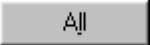
<sup>1</sup> For more controlled zooming in and out of an image, you can hold the <Ctrl> key depressed while rotating the mouse-wheel forwards (to zoom in) or backwards (to zoom out).

Close the photograph and move the cursor a few pixels eastwards to coordinate 218, 537. The reflectance is greater at this position due to the presence of bare sand (you may need to zoom in to a 7:1 ratio to see the brighter pixels). The sand habitat is illustrated in file **Sand\_habitat\_CCC.bmp**.

Once you have completed this part of the lesson, close all files without saving their contents.

## Visual interpretation of CASI imagery of Cockburn Harbour

To save you time the next colour composite has been saved as a *Bilko* “set”. A set is just a text file that tells *Bilko* (i) which three images make up the colour composite and (ii) the order in which they should be opened. The order determines which colour gun each will be displayed through, with the first being displayed through the red gun, the second through the green, and third through the blue gun. Background pixels of the CASI image are set to zero and should be treated as null values.

*Activity:* Use **File, Open** to bring up the **Open** dialog box. Select SETS (\*.set) from the **Files of type:** drop-down menu and open the set **CASI\_Cockburn\_Harbour#05+#03+#01.set**, which is a colour composite of Cockburn Harbour, South Caicos taken with the CASI. In the **Redisplay Image** dialog box check the **Null value(s):** checkbox to set null value == 0 and select Auto linear stretch as the stretch to be used. Click the  button to apply the stretch and null value settings to all three bands and open the colour composite (and its constituent bands).

Examine the image [*hint:* a zoom of about 60% allows you to see most of the image at one time]. Note that if you click on a pixel in the image and examine the Status bar of the *Bilko* window, you can see the following information displayed: (i) the zoom %, (ii) the pixel’s Universal Transverse Mercator (UTM) Easting and Northing coordinates, (iii) the pixel’s underlying data values in the CASI band #5, band #3 and band #1 images respectively, and (iv) the pixel’s display values (0–255) in the CASI band #5, band #3 and band #1 images respectively.

*Question:* 1.4. Which CASI band is displayed through the red gun, what part of the EMS is this band in and what wavelengths in nanometres does the band stretch between? Which CASI band is displayed through the blue gun, what part of the EMS is this band in and what wavelengths in nanometres does the band stretch between? [See Table 1.1.]

The wiggly edge to the image is caused by the rolling of the aircraft as it flies along. The image represents the far (eastern) side of Cockburn Harbour as viewed in the aerial photograph **Cockburn\_harbour.bmp**. The CASI sensor itself can be viewed by opening the file **Casi\_sensor.bmp** showing the instrument mounted in a specially designed door (for further details see *Image data* section above and Clark *et al.*, 1997).

Many reef habitats can be identified in this image. To familiarise you with these habitats and introduce the skills of visual interpretation, you are provided with a series of column and row coordinates (easier to type in than UTM ones), photographs and interpretation notes (Table 1.3).

*Activity:* Switch from UTM coordinates to column and row coordinates by selecting **View, Coords** (**Coords** should not be ticked/checked). Now use the **Edit, Go To** command to relate the location (coordinate) of each site to the habitat. The notes should outline the mental decisions taken when identifying each habitat. Close each photograph before moving on to the next and zoom in and out of the CASI colour composite as necessary.

**Table 1.3.** Visual interpretation of CASI imagery to identify key marine habitats.

Co-ordinates		Habitat photograph	Description of habitat	Notes on visual interpretation / recognition of habitat on CASI image
X:	Y:	file name		
630	182	<b>Brown_algae.bmp</b>	brown algae ( <i>Lobophora variegata</i> ) dominated	often located on hard substrata near the shoreline, happens to have brownish orange colour on composite
595	380	<b>Montastraea_colonies.bmp</b>	large coral heads ( <i>Montastraea annularis</i> ) on sandy bottom	distinctive heterogeneous texture: dark patches up to ~8 m across surrounded by paler sand
587	616	<b>Elkhorn_A-palmata_CCC.bmp</b>	large stands of elkhorn coral ( <i>Acropora palmata</i> )	usually located in shallow areas with high wave energy (e.g. reef crest, seaward side of islands)
490	889	<b>Montastraea_survey.bmp</b>	<i>Montastraea</i> reef – a mixed community of corals, algae and sponges. Of the hard corals, the genus <i>Montastraea</i> dominates	associated with the outer fringing reef (seaward of the reef crest or lagoon) and at depths where the wave exposure is reduced (i.e. 5 m plus)
377	852	<b>Sand_habitat_CCC.bmp</b>	sand gully in deep water (15 m depth)	high reflectance yet deep water indicating a strongly-reflecting substratum
356	498	<b>Gorgonian_plain.bmp</b>	plain dominated by soft corals (gorgonian plain)	this habitat often has a high percentage cover of bare substratum with a high reflectance. Therefore, its colour lies somewhere between sand and the shallowest areas of <i>Montastraea</i> reef
416	176	<b>Seagrass_dense.bmp</b>	dense seagrass ( <i>Thalassia testudinum</i> )	usually distinctive dark patches of considerable extent (ranging from 15 m across in higher energy areas to 50–100s m across in more sheltered areas) which appear black in deeper water. Most obvious features are homogenous consistency (texture) and sharp boundaries
531	264	<b>Seagrass_sparse.bmp</b>	sparse seagrass	fairly homogeneous texture but the tone is much lighter than dense seagrass. Other features are relatively large (10–100 m across) patch size and indistinct boundaries
426	230	<b>Seagrass_blowout.bmp</b>	seagrass “blowout”	not a habitat but an important feature created by a loss of seagrass within a seagrass bed. Characteristic elliptical shape with high contrast between sand and dense seagrass

**Activity:** When you have finished studying the photographs and honing your visual identification skills, answer the following questions, giving your reasoning.

**Question:** 1.5. What habitat would you expect to find at column and row coordinates 375, 64?

**Question:** 1.6. What habitat would you expect to find at coordinates 455, 361?

**Question:** 1.7. What habitat would you expect to find at coordinates 522, 412?



*Question:* 1.8. What habitat would you expect to find at coordinates 132, 722?

*Question:* 1.9. What habitat would you expect to find at coordinates 320, 87?

*Activity:* When you have answered the questions think about how you might a) define habitats so that other people will know what you mean, and b) how you might use remote sensing to help plan field surveys. Leave the CASI images open as you will need these later.

The habitats you have looked at in this lesson were defined from ecological field data. Bear in mind, however, that one person's understanding of a "habitat type" may vary from the next person's and thus, it is important to make a clear definition of habitats prior to undertaking a study. The objectives of most habitat mapping exercises fall into four groups:

- (i) *ad-hoc* definition of habitats without collecting field data,
- (ii) application-specific studies focused on only a few habitats,
- (iii) geomorphological studies, and
- (iv) ecological studies.

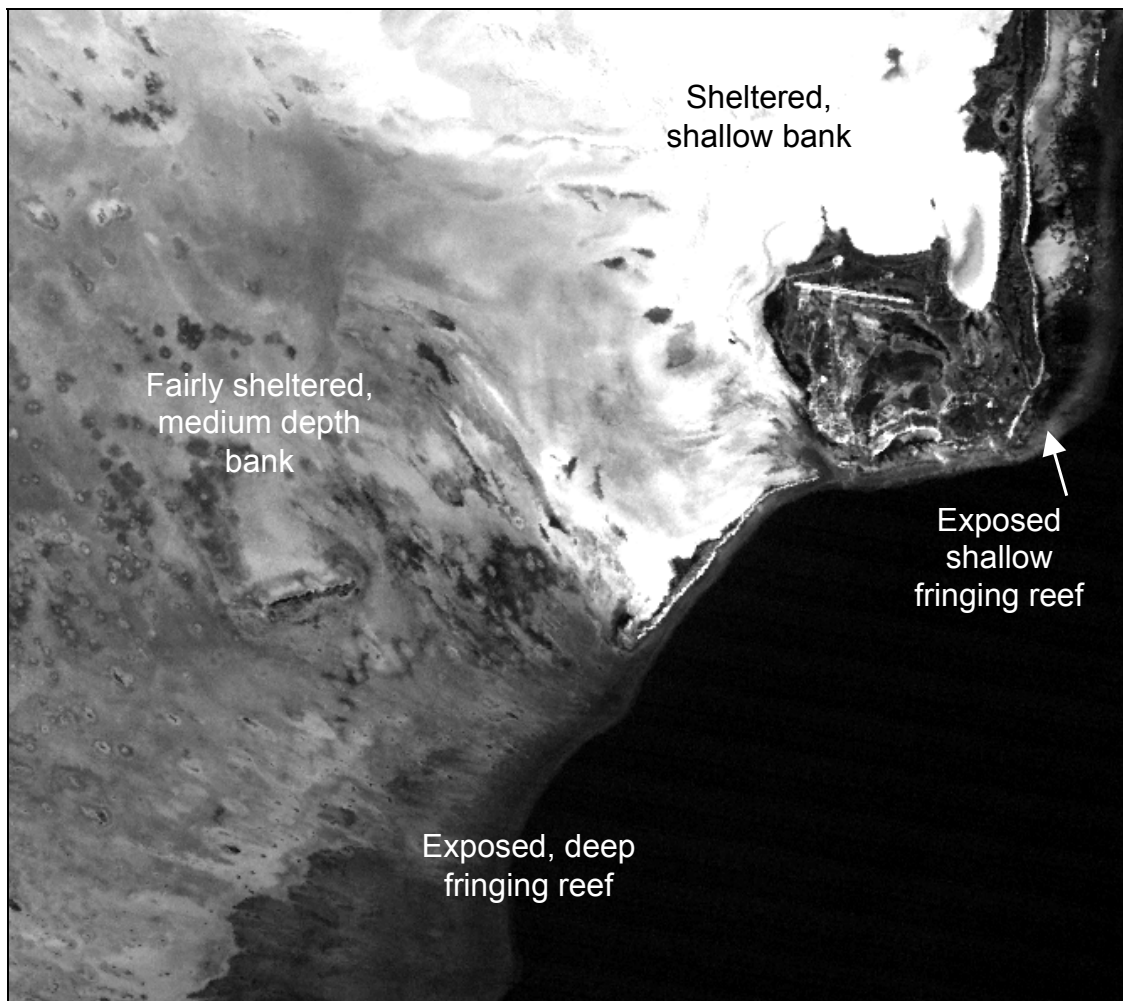
An *ad-hoc* approach to defining habitats is relatively cheap but is only recommended in the cases where the accuracy of habitat maps is not important. Habitat-specific studies (e.g. a seagrass study) should include the habitat of interest and those additional habitats that are most likely to be confused with it (e.g. macroalgae is easily confused with seagrass), thus permitting the accuracy of mapping to be evaluated. Geomorphological classifications can be assigned to imagery with little or no field work. The establishment of objective ecological habitat classifications (e.g. assemblages of bottom-dwelling species and substrata) usually requires multivariate analysis of field data, such as hierarchical cluster analysis. These methods simplify the dataset and provide a clearly defined basis to the classification scheme. The characteristic and discriminating features of each habitat can be identified and used to make a clear and unambiguous description of the classification scheme, thus facilitating its use and interpretation, and allowing later surveys in monitoring studies to compare their data. For further information, you are directed to Chapter 9 of the *Remote Sensing Handbook for Tropical Coastal Management*.

### **Use of visual interpretation when planning field surveys**

Field survey is essential to identify the habitats present in a study area, to record the locations of habitats for supervised multispectral image classification (i.e. creation of habitat maps – see Lesson 8 of this module) and to obtain independent reference data to test the accuracy of resulting habitat maps. The efficiency of a field survey campaign can be maximised by making a visual interpretation of imagery during the planning stage.

Visual interpretation of imagery helps plan field survey in the following ways:

1. *Providing the location of known (and often target) habitats.*
2. *Providing the location of unknown habitats (i.e. habitats that cannot be identified using visual interpretation skills).* These habitats might become a priority of the field survey.
3. *Identifying the main physical environments of the study area.* The physical environment (e.g. depth, wave exposure, and aspect) will, to a large extent, control the distribution and nature of marine habitats. Relative depths can be inferred from most optical imagery (deeper areas are darker) and if the prevailing direction of winds and waves are known, the area can be stratified according to the major physical environments (e.g. Figure 1.3). If possible, each of these areas should be included in the survey, thus maximising the chances that the full range of marine habitats will be surveyed.




**Figure 1.3.** Principal physical environments of the Eastern Caicos Bank

4. *Identify the range of environmental conditions for each habitat.* Coastal areas will often possess gradients of water quality and suspended sediment concentration (e.g. plumes of sediment dispersing from an estuary). Changes in water quality across an image will alter the spectral reflectance of habitats measured by the remote sensor. For example, the spectral reflectance recorded for, say, coral sand will be greater in clear water than in turbid water. Field survey should therefore incorporate areas with different water quality so that the variation in spectral reflectance of each habitat is known throughout the image. Failure to do so may increase the degree of spectral confusion during image classification (or visual interpretation) and therefore the mis-assignment of habitat categories. If field surveys represent a full range of physical environments, the survey data can also be used to test the accuracy of the habitat maps and highlight the extent of any inaccuracies.

5. *Stratification of survey effort.* The field survey should attempt to include a reasonable number of samples from each habitat of interest. To achieve this goal efficiently, the distribution and coverage of habitats should be considered carefully. For example, the shallow sheltered bank in Figure 1.3 is visibly homogenous suggesting that the habitat type is fairly uniform throughout the area. It follows that relatively few field surveys should adequately represent this area; thus survey effort can be concentrated in areas with greater heterogeneity (e.g. the complex region of patch reefs in the fairly sheltered area with medium depth, Figure 1.3). For more details on sampling effort and accuracy assessment, readers are referred to the *Remote Sensing Handbook for Tropical Coastal Management* (Chapters 4, 10 and 19) and Congalton (1991).

## Differential attenuation of light through the water column

We will now briefly look at the problems created by the fact that longer visible wavelength light (red end of the spectrum) is absorbed more as it passes through the water column than shorter wavelength light (blue end of the spectrum). You will firstly compare the light penetration in the 3 CASI bands and then examine one habitat (sand) at different depths.

*Activity:* Use **Image, Connect** to connect and stack the three constituent images which make up the CASI colour composite (**CASI\_Cockburn\_Harbour#01.dat**, **CASI\_Cockburn\_Harbour#03.dat** and **CASI\_Cockburn\_Harbour#05.dat**). You should now have a stacked set with the top image (@1) being **CASI\_Cockburn\_Harbour#01.dat** and the bottom image (@3) being **CASI\_Cockburn\_Harbour#05.dat**. Use either the <Tab> key or the Loop button  to compare shallow water areas towards the top of the image for each band in turn. Note the good contrast in CASI bands #1 and #3 and relatively poor contrast and lower radiance in band #5 in the red part of the spectrum.

Repeat your comparison for the middle of the image and note how the red light is failing to return any significant signal from the seabed at depths over about 5 m. Repeat again for the south part of the image where water is deepest (around 18 m).

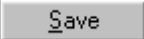
Your inspection of the three bands highlights two central problems in remote sensing of submerged habitats. Firstly, the same habitat will have very different radiances (pixel values) at different depths. Secondly, the way these values change with depth will be different for different wavebands. If we wish to classify submerged habitats on the basis of their multispectral reflectances (spectral signatures), this clearly presents a major problem. How you can deal with the problem is dealt with in Lesson 7. Meanwhile you can get a rough idea of the difference in the rates of attenuation of the red and blue wavebands by looking at sand pixels at 2 m and 15 m depth.

*Activity:* Close the stack (without saving anything) and make the colour composite the active image. Place the image cursor on coordinate 319, 860 in the sand gully in about 15 m depth. Note the underlying data values for each of the three composite bands from the Status bar (so that you can answer the questions below). Then place the image cursor on coordinate 653, 509 on the shallow sand patch at about 2 m depth off Dove Cay and note the underlying data values for each of the three composite bands here. In each case the habitat is white coral sand but in the first case it is deep and in the second shallow.

*Question:* 1.10. (a) For the red band, what percentage of the 2 m deep pixel value is the 15 m deep pixel value? (b) For the blue band, what percentage of the 2 m deep pixel value is the 15 m deep pixel value? [Give your answer to the nearest whole %.]

## Saving colour composites as pictures

If you need to illustrate a report (e.g., a *Word* document), scientific paper, or *Powerpoint* presentation with colour images like the colour composite you have been working with, you should save the composite as a Windows bitmap (**.bmp**) file in *Bilko*. However, if you wanted to continue to work with a colour composite image in *Bilko*, you would save it as a set.

*Activity:* With the colour composite (**CASI\_Cockburn\_Harbour#05+#03+#01.set**) as the active image select **File, Save As**. In the **Save As** dialog box, choose Windows **.bmp** as the **Save as type:** and click on . This will save the composite as a 24-bit Windows bitmap, giving a true colour image; this file can be inserted into *Word* documents or *Powerpoint* presentations using the **Insert, Picture, From File** menu option in these packages. Windows **.bmp** files can also have lettering, scale bars, labels, etc. added in photo editing packages, in *Powerpoint* or in *Word*. You may wish to experiment with this at some time.

Close all files (**Window, Close All**) and then reopen the Windows bitmap you have just created. Note that it faithfully shows the colour composite, with the **Redisplay** options you had applied at the time of saving. However, also note that it no longer has any UTM coordinates and that it lacks the three colour bars underneath, which indicate the stretches applied to each band. It is no longer a set of three 16-bit images, just a picture of how these were displayed at the time you saved the image. Close the bitmap.

### **References**

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## APPENDIX 1.1

**LANDSAT THEMATIC MAPPER (TM) AND ENHANCED THEMATIC MAPPER (ETM+) SENSORS**

The Landsat Thematic Mapper (TM) and its successor the Enhanced Thematic Mapper (ETM+) have been operational since 1984 following the launch of Landsat-4. The spatial resolution for the TM sensor is 30 m except for Band 6 which measures emitted thermal infra-red radiation and has a resolution of 120 m. For the ETM+ sensor the Band 6 spatial resolution was improved to 60 m and a panchromatic band (band 8: spectral range 520–900 nm) with a spatial resolution of 15 m was added. The radiometric resolution is 8 bits (256 grey levels). The swath width for the sensor is 185 km. At the time of this research (1995) the Thematic Mapper was only operational on Landsat-5 having failed on Landsat-4 in August 1993. Currently (2005) Landsat-7, launched in April 1999, is providing ETM+ imagery.

The spectral characteristics of the Landsat TM bands are as follows (ETM+ characteristics are included in parentheses where they differ):-

TM Band	Colour	Wavelengths (nm)	Uses
1	Blue	450–520 (450–515)	Good water penetration; useful for mapping shallow coastal water. Strong vegetation absorbance; good for differentiating soil from vegetation, and deciduous from coniferous vegetation.
2	Green	520–600 (525–605)	Designed to measure visible green reflectance peak of vegetation for vigour assessment. Also useful for sediment concentrations in turbid water.
3	Red	630–690	Strongly absorbed by chlorophyll; an important band for vegetation discrimination. Also good for detecting ferric (red coloured) pollution.
4	Near Infra-red	760–900 (750–900)	Very strong vegetation reflectance; useful for determining biomass. High land/water contrast so good for delineating water bodies/coastlines.
5	Short Wave Infra-red	1550–1750	Moisture sensitive; indicative of vegetation moisture content and soil moisture.
6	Thermal Infra-red	10,400–12,500	Used in vegetation stress analysis, soil moisture discrimination, and thermal mapping.
7	Short Wave Infra-red	2080–2350 (2090–2350)	Good for discriminating rock types.
PAN	Panchromatic	520–900	15 m spatial resolution (ETM+ only)

Images are produced by reflecting the radiance from 30 m wide scan lines on the Earth's surface to detectors on board the satellite using an oscillating mirror. Each scan line is 185 km long (thus the **swath width** or width of ground covered by the sensor in one overpass is 185 km). The Instantaneous Field of View (IFOV) of the TM sensor (roughly equivalent to the **spatial resolution**) is a 30 m x 30 m square on the Earth's surface except for the thermal infra-red Band 6 where it is 120 m x 120 m in TM and 60 m x 60 m in ETM+. A 15 m x 15 m pixel size panchromatic band was also added with

ETM+. Each **pixel** in a TM multispectral digital image is thus a measurement of the brightness of the radiance from a 30 m x 30 m square on the Earth's surface.

Because the satellite is moving so fast over the Earth's surface, the TM sensor had to scan 16 lines at a time or 4 lines at a time for Band 6 (thus covering 480 m along track on each scan). Since the TM sensor measures the radiance in seven different wavebands at the same time, it thus has  $6 \times 16 + 4 = 100$  detectors in total. Each detector converts the recorded irradiance into an electrical signal, which is converted to an 8-bit number (256 grey levels). The **radiometric resolution** of the TM sensor is thus 4 times that of the Landsat Multi-Spectral Scanner.

The image size is 185 km across by 172 km along-track (170 km on ETM+); equivalent to 5760 lines by 6928 pixels. With seven wavebands each TM scene thus consists of about 246 Mbytes of data!

Further information on Landsat can be found at:

<http://geo.arc.nasa.gov/esd/esdstaff/landsat/landsat.html>

and

<http://landsat.gsfc.nasa.gov/>

## APPENDIX 1.2

### SPOT

SPOT (Satellite Pour l'Observation de la Terre) is a remote sensing satellite developed by the French National Space Centre (CNES - Centre National d' Études Spatiales) in collaboration with Belgium and Sweden. SPOT-1 was launched in February 1986, SPOT-2 in January 1990, SPOT-3 in September 1993 (failed in November 1997), SPOT-4 in March 1998 and SPOT-5 in May 2002.

The SPOT images for these lessons are from the High Resolution Visible (HRV) sensor carried by SPOT-1 to SPOT-3. Each of these satellites carried two High Resolution Visible (HRV) sensors. The HRV sensor is a "pushbroom scanner" which can operate in either multispectral mode (3 wavebands) at 20 m resolution (XS), or in panchromatic mode (1 waveband) at 10 m resolution (XP or Pan). Radiometric resolution is 8 bits (256 grey levels) in multispectral mode and 6 bits (64 grey levels) in panchromatic mode. The swath width is 60 km per HRV sensor and images are supplied as 60 x 60 km scenes. The two HRV sensors overlap by 3 km giving a swath width of 117 km for the satellite as a whole. SPOT-4 and SPOT-5 sensors have enhanced capabilities with an additional short-wave infrared band on SPOT-4 and enhanced spatial resolution for all bands on SPOT-5 (see <http://www.spotimage.fr/> for details).

The mirror which focuses the light reflected from the ground-track onto the detector array can be angled by ground control through  $\pm 27^\circ$  allowing off-nadir viewing within a strip 475 km to either side of the ground-track. Using the mirror, stereoscopic imagery can be obtained by imaging a target area obliquely from both sides on successive passes. The mirror also allows target areas to be viewed repeatedly (revisited) on successive passes such that at the Equator an area can be imaged on 7 successive days, whilst at latitude  $45^\circ$  eleven revisits are possible.

The detectors are Charge Coupled Devices (CCDs)<sup>†</sup> which form a solid state linear array about 8 cm long. Each pixel across the scan line is viewed by an individual detector in the array so that in panchromatic mode there are 6000 detectors each viewing a 10 m square pixel, whilst in multispectral mode there are 3000 detectors each viewing a 20 m square pixel on the Earth's surface. The linear array is pushed forward over the Earth's surface by the motion of the satellite, hence the name "pushbroom scanner".

<sup>†</sup>CCDs are light sensitive capacitors which are charged up in proportion to the incident radiation and discharged very quickly to give an electrical signal proportional to the radiance recorded.

#### Orbital characteristics

- 1) Near-polar sun-synchronous orbit.
- 2) Altitude of 832 km.
- 3) Equatorial crossing time at 10:30 h.
- 4) Repeat cycle 26 days.

#### HRV sensor spectral characteristics (SPOT 1 to 3)

Multispectral (XS)	Pixel size	Spectral band
Band 1: Green	20 m	500–590 nm
Band 2: Red	20 m	610–680 nm
Band 3: Near-IR	20 m	780–890 nm
Panchromatic (XP)	10 m	500–730 nm

Images in either multispectral mode (XS) or panchromatic mode (XP) can be purchased.

## APPENDIX 1.3

### IKONOS

The launch of the IKONOS-2 satellite in September 1999 provided the first commercial high-resolution satellite imagery. The spectral resolution for its 4 multispectral bands are more or less identical to those of Landsat TM (and ETM+) bands 1 to 4, but its spatial resolution is such that for each Landsat TM pixel there are around 50 IKONOS multispectral pixels or 900 panchromatic pixels.

#### IKONOS sensor spectral characteristics

Multispectral	Pixel size	Spectral band
Band 1: Blue	4 m	450–520 nm
Band 2: Green	4 m	510–600 nm
Band 3: Red	4 m	630–700 nm
Band 4: Near-IR	4 m	760–850 nm
Panchromatic	1 m	450–900 nm

Radiometric resolution is 11 bits compared to 8 bits for Landsat TM (ETM+).

#### Orbital characteristics

- 1) Near-polar sun-synchronous orbit.
- 2) Altitude of 680 km.
- 3) Equatorial crossing time at 10:30 h.

Details of IKONOS can be found at:

<http://www.spaceimaging.com/products/ikonos>



## APPENDIX 1.4

### Compact Airborne Spectrographic Imager (CASI)

CASI is a pushbroom imaging spectrograph designed for remote sensing from small aircraft. The instrument used to obtain the images used in these lessons comprises a two-dimensional 578 x 288 array of CCD (Charge Coupled Device) detectors. It is light (55 kg) and can be mounted in an aircraft as small as a Cessna 172 (single-engine, four seats). A modified Cessna door in which the instrument can be mounted is available so that CASI can be mounted without making holes in the aircraft. It requires only 250 Watt of power and can be run off a light aircraft's power circuit in most cases. If not, it can be run off a heavy-duty lead-acid battery. CASI is manufactured by ITRES Research of Calgary, Alberta, Canada. Details of later CASI models (CASI-2 and CASI-3 systems) can be found at:

<http://www.itres.com/docs/sensors.html>

Details of the CASI sensor used to obtain the images for these lessons follow. The width of the array was 578 detectors, which in imaging mode viewed a strip 512 pixels wide underneath the aircraft (the remaining 64 detectors being used for calibration purposes). The angle of view was 35° and the width of this strip and size of the pixels was determined by the height of the aircraft. At an altitude of 840 m (2750 feet) pixels were 1 m wide, at about 2500 m they were 3 m wide. The speed of the aircraft and scanning rate of the instrument are adjusted to make the pixels square. The instrument could scan at up to 100 lines per second and was designed for spatial resolutions of 1–10 m. The 288 detectors per pixel allowed up to 288 different spectral bands (channels) to be sampled across a spectral range of about 400–900 nm. The minimum bandwidth was 1.8 nm. The radiometric resolution was 12 bits (4096 grey levels).

In **imaging mode** a set of up to 16 spectral bands were chosen and the instrument was programmed to record in these bands. At 1 m resolution it was found feasible to record in only 8 wavebands because of the rate of data acquisition required, whilst at 3 m resolution it was possible to record in 16 wavebands. A 16 band marine band-setting optimised for water penetration was used for flight-lines over water, and a 16 band terrestrial band-setting optimised for mangrove and vegetation mapping was used over land. Band settings could be switched in flight. Locating pixels accurately for ground-truthing at this high spatial resolution requires a good **differential global positioning system** (DGPS).

In **multispectrometer mode** the instrument recorded in 288 different 1.8 nm wide bands for up to 39 look directions (pixels at a time) across the swath width. This allowed detailed spectral signatures of pixels to be built up. The difficulty is in determining precisely where these pixels are and then ground-truthing them so that spectral signatures can be assigned to defined habitats.

CASI-3 offers spatial resolutions as good as 0.5 m and at 1 m spatial resolution has a swath width of 1480 m as opposed to the 512 m offered by the instrument we used in 1995. It also has a radiometric resolution of 14-bits and spectral range of 400 to 1050 nm.

