8: MAPPING THE MAJOR INSHORE MARINE HABITATS OF THE CAICOS BANK BY MULTISPECTRAL CLASSIFICATION USING LANDSAT TM

Aim of Lesson

To learn how to undertake a simple supervised classification of a Landsat TM image to show the major marine and terrestrial habitats of the Caicos Bank.

Objectives

1. To prepare a mask for the land areas of the Landsat TM image and apply this mask to the depth-invariant bottom index images to be used for classification.

2. To learn how to link UTM coordinate referenced field survey data of shallow water marine habitats to the Landsat TM image to derive simple spectral signatures for the major marine habitats (sand, seagrass, algae, gorgonian plain, coral reef).

3. To understand the concepts underlying a simple box classification of marine habitats into sand, seagrass, algae, gorgonian plain, and coral reef, and perform the classification of each habitat in turn.

4. To learn how to combine these separate images (GIS layers) into a single image and use an appropriate palette to display the habitats.

Background Information

This lesson relates to material covered in Chapters 9–11 of the *Remote Sensing Handbook for Tropical Coastal Management* and readers are recommended to consult this for further details of the techniques involved. The lesson introduces you to multispectral classification of imagery using a simple two-dimensional box-classification of the "feature space" of two depth-invariant bottom index images.

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; these are introduced in Tutorial 10 of the *Introduction to using the Bilko 3 image processing software*. Some calculations need to be performed independently; these can either be carried out on a spreadsheet such as *Excel* or using a calculator.

Image data

The image used as the basis for this lesson was acquired by Landsat-5 TM on 22nd November 1990 at 14.55 hours Universal Time (expressed as a decimal time and thus equivalent to 14:33 GMT). The Turks & Caicos are on GMT – 5 hours so the overpass would have been at 09:33 local time. This image has been geometrically corrected (see Lesson 3), radiometrically and atmospherically corrected (Lesson 4), and finally water column corrected (Lesson 7) to produce two depth-invariant bottom index bands; one from bands #1 and #3 (***Depth-invariant_LandsatTM#1_#3.dat***) and one from bands #2 and #3 (***Depth-invariant_LandsatTM#2_#3.dat***). The third depth-invariant band (from bands #1 and #2) will not be used here. The sub-scenes provided are of the South Caicos area only and are 32-bit floating-point images, i.e. each pixel is stored as a floating-point number and occupies four bytes. To allow a mask image to be made to mask out the land areas, you are also provided with the band #5 (near infra-red) image of the same area (***LandsatTM_Caicos#05.gif***).

Field survey data

You are provided with a spreadsheet (***Habitats_Lesson8.xls***) containing field survey data on seven habitat classes:

1. Dense seagrass,
2. Sparse seagrass,
3. Sand,
4. Dense *Montastraea* reef,
5. Gorgonian plain,
6. *Lobophora* dominated macroalgal areas,
7. Coral patch reefs.

For each habitat class you are provided with GPS-derived UTM coordinates of 7 sites where the habitat occurred. The reflectance values for each ground-truthing site in each of the two depth-invariant bottom index image bands (***Depth-invariant_LandsatTM#1_#3.dat*** and ***Depth-invariant_LandsatTM #2_#3.dat***) are provided for most sites but you will be asked to collect the spectra for two sand and two sparse seagrass sites.

Lesson Outline

The first task is to mask out the land areas on the two depth-invariant bottom index images (***Depth-invariant_LandsatTM#1_#3.dat*** and ***Depth-invariant_LandsatTM#2_#3.dat***). We will use the near-infrared Landsat TM band #5 image to make the mask and then multiply the depth-invariant images by it.

Making a land mask

The main task in this lesson is to classify major submerged habitats. To allow contrast stretches, which will display these habitats optimally, and to remove the distraction of terrestrial habitats, which are best classified separately using a combination of infra-red and visible wavebands, you should mask out the land areas. This is easily achieved using a Landsat TM band #5 infra-red image (***LandsatTM_Caicos#05.gif***) where there will be very little reflectance from water covered areas but considerable reflectance from land areas. This allows water and land areas to be fairly easily separated on the image and a mask of either land or water to be created with a simple Formula document.

A land mask image has all land pixels set to zero and all water pixels set to 1, so when used to multiply another image it leaves sea pixel values unchanged but sets all land pixels to zero.

Activity: Launch *Bilko* if you have not already done so. Open the two depth-invariant images (***Depth-invariant_LandsatTM#1_#3.dat*** and ***Depth-invariant_LandsatTM#2_#3.dat***), setting null value as zero and applying histogram equalization stretches to each image in the **Redisplay Image** dialog box. Also open the band #5 image (***LandsatTM_Caicos#05.gif***). Connect the three images together as a tiled set using the **Image, Connect** command. Use the **Selector** toolbar to ensure that ***LandsatTM_Caicos#05.gif*** becomes image 1, ***Depth-invariant_LandsatTM#1_#3.dat*** becomes image 2, and ***Depth-invariant_LandsatTM#1_#3.dat*** becomes image 3.

The next step is to make a mask using ***LandsatTM_Caicos#05.gif***. You need to produce an image from it that has all sea pixels set to 1 and all land pixels to 0. Minimize the two depth-invariant images and apply an automatic linear stretch to the original ***LandsatTM_Caicos#05.gif*** image. Note that the sea pixels are uniformly dark whilst the land pixels are variable but generally bright. It will thus be fairly easy to find out what the maximum reflectance of the sea pixels are, then to consider any pixels above this threshold value as being land. Use **View, Coords** to switch off UTM coordinates.

Activity: You can either move the cursor around in areas which are clearly sea and note the highest pixel value you record or copy some 10 x 10 groups of sea pixels to an *Excel*

spreadsheet and use the MAX function or inspection to find out what the largest value is. [*Suggestion:* Use **Edit, Go To** to select 10 x 10 pixel box starting at coordinates 382, 82 off the east coast of South Caicos, **Copy** this block of pixels and **Paste** it to a spreadsheet. Note the highest value. Repeat with a 10 x 10 pixel box from the salinas on South Caicos starting at coordinates 300, 105.]

Question: 8.1. What is the highest pixel value in areas that are clearly water covered?

Having established what the highest reflectance from water covered areas is, you need to create a Formula which will set all pixels which are brighter (greater than) than this threshold value to zero and all pixels which are less than the threshold to 1.

This requires a formula of the type:

<div align="center">

IF (@1 <= threshold) 1 ELSE 0 ;

</div>

where @1 is the **LandsatTM_Caicos#05.gif** image. The formula takes each pixel in the @1 image and compares it to the threshold value, then IF the pixel has a value which is less than or equal to (<=) the threshold value it sets the output image pixel to 1. Otherwise (ELSE) the output image pixel is set to 0. Thus the output image has all land pixels set to 0 and all water pixels set to 1.

Activity: Open a new Formula document. Type in some title as a comment (i.e. preceded by #) so that you will remember what the formula does. Set up a constant statement (CONST name = value ;)which sets a constant (CONST) called "threshold" (omit the quotation marks!) equal to the highest pixel value you found in the water covered areas of the Landsat TM band #5 image. Then type in the formula as above. [*Remember:* All formula statements have to end in a semi-colon.] Use the **Options!** menu available from a Formula document to ensure that the **Output Image Type:** will be the same as @1 (or an 8-bit unsigned integer image), and that there is <u>no</u> special handling for nulls.

   Copy the formula and **Paste** it to the connected images window where **LandsatTM_Caicos#05.gif** is @1. The resultant image should look all black since the brightest pixel has a value of only 1. Save this image immediately as **Landmask_lesson8.gif**. Apply an automatic linear contrast stretch to the image. All the land should be black and all the water areas white.

   Close the connected images window, **LandsatTM_Caicos#05.gif**, and the formula document (without saving any changes).

You now need to create two new depth-invariant bottom index images with the land masked out. This is achieved by multiplying the images by the land mask image.

Activity: **Connect** **Landmask_lesson8.gif** with the two depth-invariant images and use the **Selector** toolbar to make **Depth-invariant_LandsatTM#1_#3.dat** image 1, **Depth-invariant_LandsatTM#2_#3.dat** image 2, and **Landmask_lesson8.gif** image 3. Then open a new Formula document. You want to multiply each of the depth-invariant images by the mask to produce two output images which will be the depth-invariant bottom index images with the land areas masked out. This will require two simple formula statements.

Question: 8.2. What two formula statements are required to make the two masked images?

Activity: When you are satisfied with your formula statements, ensure that the **Output Image Type:** will be the same as @1 (or 32-bit floating point), and that there is <u>no</u> special handling for nulls. Apply your formula to the connected images and inspect the resultant images to see if the land pixels have been set to zero as expected. Save the new images as **Depth-invariant_masked#01.dat** (for the **Depth-invariant_LandsatTM#1_#3.dat** masked image) and **Depth-invariant_masked#02.dat** (for the **Depth-invariant_LandsatTM#2_#3.dat** masked image). Close the connected

images window, the **Landmask_lesson8.gif** image, and the unmasked depth-invariant images.

Determining the spectral signatures of the major submerged habitats using UTM coordinate referenced field survey data

In this section you will use field survey data on where different habitats are located on the images (in **Habitats_Lesson8.xls**) to derive spectral signatures for major marine habitats and then use these signatures to classify the image. The classification method that you will test, is to create a simple box (parallelepiped) classifier for each habitat using the two depth-invariant bottom-index images. That is, you are seeking to define discrete two-dimensional areas in feature space that relate to specific habitats.

The first step is to find out what reflectance values in each depth-invariant band relate to which habitats.

Activity: Open the spreadsheet file **Habitats_Lesson8.xls**. This gives a listing of the training sites that provide the basis of your supervised classification of the images. Seven field survey sites for each habitat are included with the pixel values for each site in each of the depth-invariant images. However, two sand and two sparse seagrass sites are missing the image data values from two survey points. Once you have these four data values you will be able to calculate the maxima and minima (box limits) for each habitat in each depth-invariant image. Switch back to *Bilko*.

Connect the **Depth-invariant_masked#01.dat** and **Depth-invariant_masked#02.dat** images as a <u>stack</u>. Make sure **View, Coords** is checked, then use **Edit, Go To** to locate the relevant pixels, which are listed in Table 8.1 for your convenience. Once at a GPS location, you can use the **<Tab>** key to move to the same position on the other image and read off its value. Enter the pixel values to **3 decimal places** in Table 8.1.

Table 8.1. Locate the pixels nearest to the GPS coordinates from the field survey and fill in the missing pixel values (rounded to 3 decimal places).

GPS coordinates		Depth-invariant bottom-index bands		
Easting (X:)	Northing (Y:)	TM bands #1/#3	TM bands #2/#3	Habitat
237382	2378154			Sparse seagrass
237176	2378235			Sparse seagrass
241743	2381866			Sand
242177	2382234			Sand

Activity: Switch back to the **Habitats_Lesson8.xls** spreadsheet and enter the missing values. The formulae already entered under the sparse seagrass and sand columns should automatically calculate the maxima and minima for these two habitats. Transfer the maximum and minimum data to Table 8.2, rounding the maxima and minima to **2 decimal places.** The reason for this is that if you have too many decimal places, it is difficult to see the wood for the trees.

Inspect the completed Table 8.2 and note that sand and possibly sparse seagrass appear to be fairly readily separable from other habitats on the basis of their depth-invariant bottom-index values whilst there appears to be a lot of overlap in the other classes. You will probably agree that it is very difficult to see the relationship of the signatures in the table in the two bands.

To see whether the signatures and box-classifiers based on the maxima and minima are likely to allow you to classify the habitats, you need to plot the pixel values in one band against those in the other

band and draw in the boundaries of the boxes. To save time, this has already been done using your spreadsheet data and is displayed as Figure 8.1. This figure shows the distribution of the habitats in a two-dimensional "feature space" based on their pixel values in the two depth-invariant bands. Study this figure and answer the following questions.

Question: 8.3. Which two habitats are clearly separable from all other habitats?

Question: 8.4. Which two habitats occupy very similar areas in feature space?

Question: 8.5. Which two habitats are likely to be confused with dense *Montastraea* reef patches?

Question: 8.6. With which two habitats is gorgonian plain likely to be confused?

Table 8.2. Minimum and maximum reflectances in depth-invariant bottom index images for 7 major marine habitats. (Taken from completed *Habitats_Lesson8.xls* and rounded to 2 decimal places.)

Habitat class	TM bands #1/#3 depth-invariant		TM bands #2/#3 depth-invariant	
	Minimum	Maximum	Minimum	Maximum
Dense seagrass				
Sparse seagrass				
Sand				
Dense *Montastraea* reef				
Gorgonian plain				
Lobophora dominated algal areas				
Coral patch reef				

Clearly it is not feasible to separate *Lobophora* dominated algal areas from coral patch reefs using just these two depth-invariant bands. Thus these two habitats need to be combined for classification.

Activity: Combine the two classes and calculate the minima and maxima for a combined class and enter the results in Table 8.3.

Table 8.3. Combined class boundaries for *Lobophora* dominated algal areas and coral patch reefs.

Habitat class	TM bands #1/#3 depth-invariant		TM bands #2/#3 depth-invariant	
	Minimum	Maximum	Minimum	Maximum
Lobophora dominated algal areas and coral patch reefs				

This improves the classification scheme but two further anomalies need addressing. As is evident from Figure 8.1 the *Montastraea* reef class swallows the dense seagrass class because of two outliers. For the purposes of this simple box-classification it is perhaps best to risk misclassification of some of the *Montastraea* reef by restricting the *Montastraea* class to a box around the five training sites which group together (Figure 8.2). Similarly, the one gorgonian plain outlier with a high depth-invariant TM band #2/#3 bottom-index results in a lot of overlap with the coral patch reef/*Lobophora* class. Restricting the gorgonian plain class box to the remaining points risks leaving gorgonian plain unclassified but should improve classification of the coral patch reef/*Lobophora* class. The revised box-classifier boundaries, which reflect the classification scheme in Figure 8.2 are listed below in Table 8.4.

Figure 8.1. Box-classification using full range of values for all seven classes.

Depth-invariant bottom index (TM bands 1 and 3)

Legend:
● Dense seagrass
○ Sparse seagrass
△ Sand
✴ Dense Montastrea reef
■ Gorgonian plain
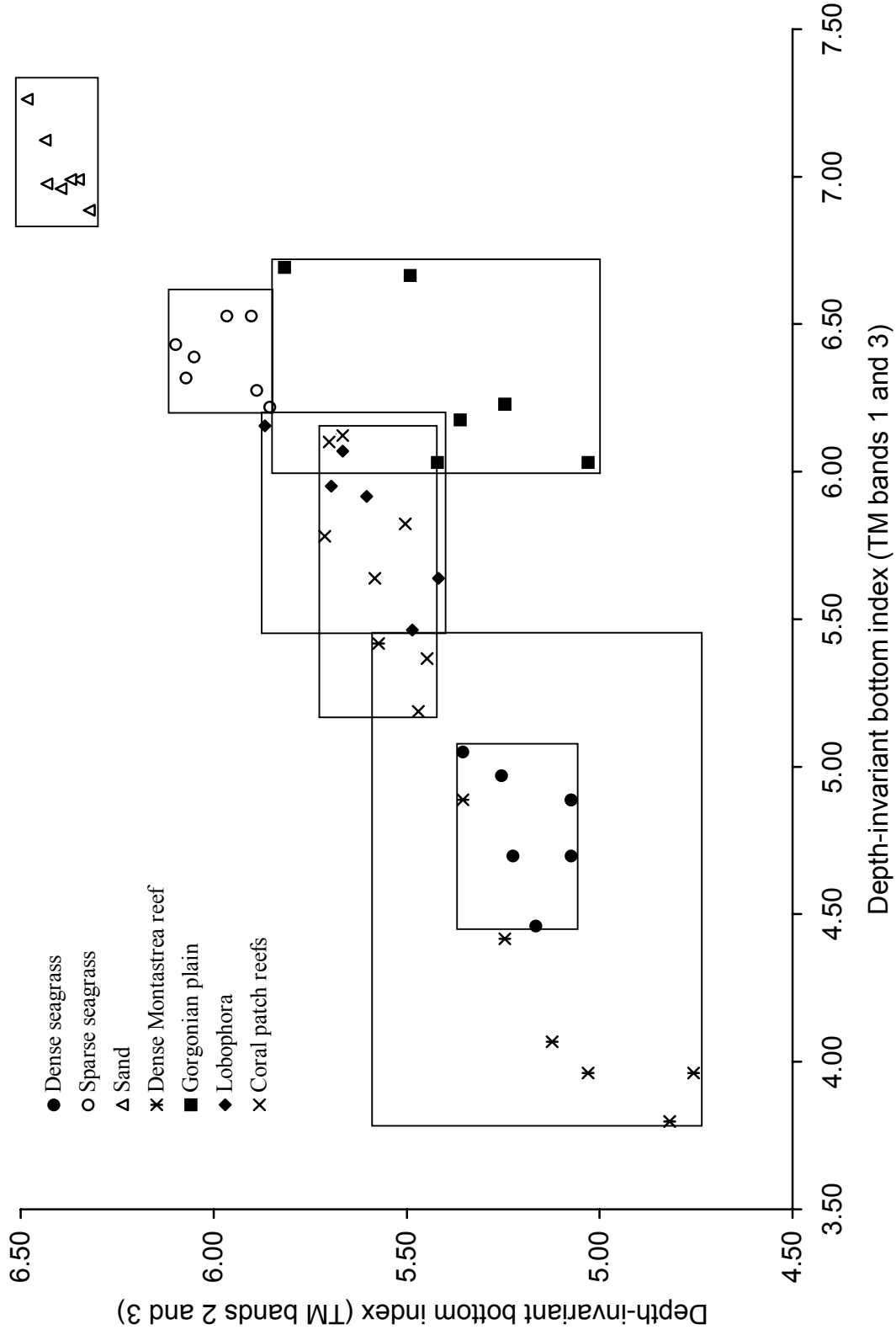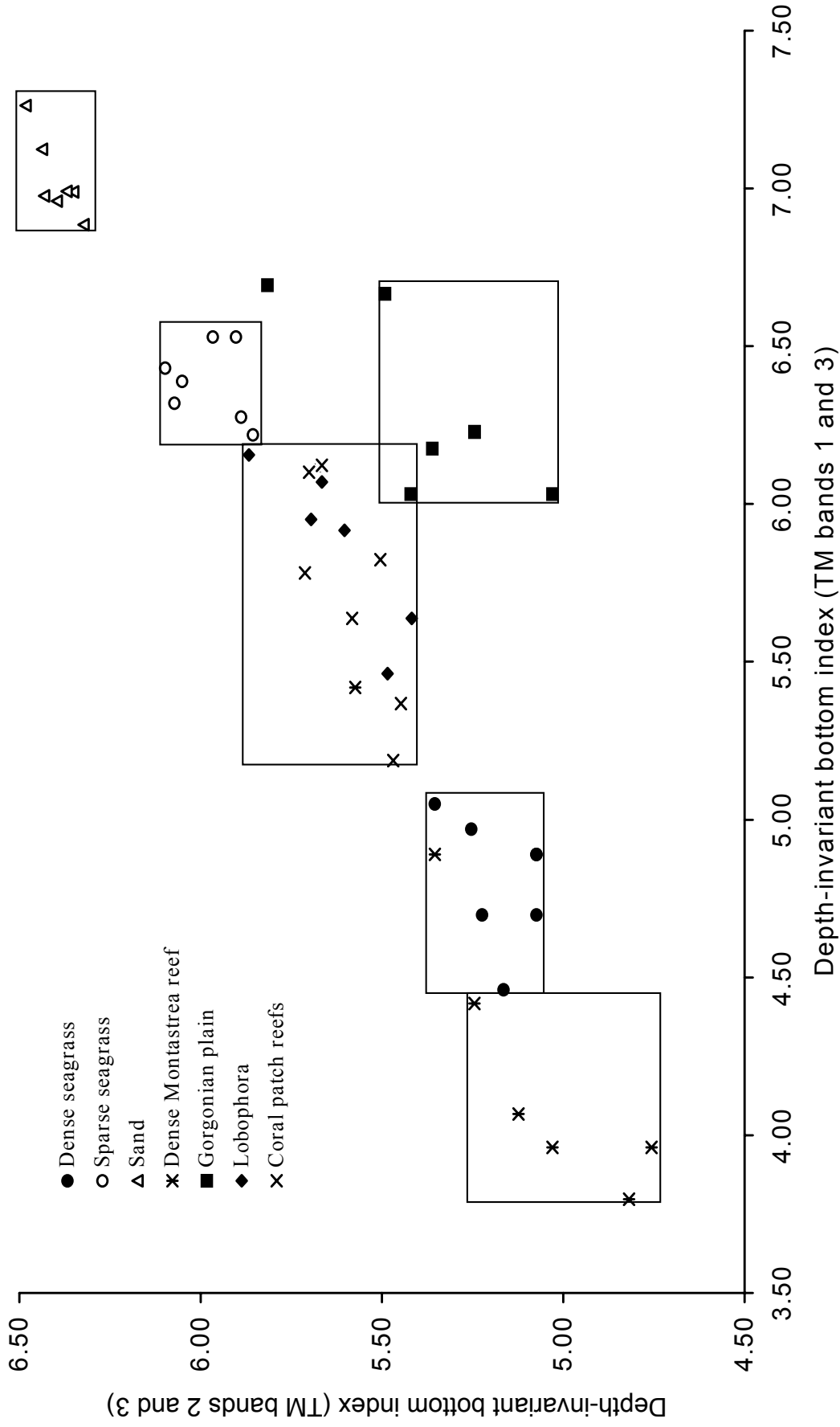◆ Lobophora
✕ Coral patch reefs

Figure 8.2. Box-classification where *Lobophora* and coral patch reef classes are merged, some gorgonian plain is left unclassified, and some dense *Montastraea* reef class is mis-classified as dense seagrass or a coral patch reef/*Lobophora*. However, this scheme is likely to produce a better map than Figure 8.1.

Dense seagrass
Sparse seagrass
Sand
Dense Montastrea reef
Gorgonian plain
Lobophora
Coral patch reefs

Depth-invariant bottom index (TM bands 1 and 3)

Depth-invariant bottom index (TM bands 2 and 3)

Bear in mind that we have used a *very small* sample of field survey points in constructing our classification and thus may be underestimating the spread of values in feature space. This could lead to a lot of the image being unclassified.

Table 8.4. Minimum and maximum reflectances in depth-invariant bottom index images for 6 major marine habitats, using box-classifiers illustrated in Figure 8.2. Changes are in bold type.

Habitat class	TM bands #1/#3 depth-invariant		TM bands #2/#3 depth-invariant	
	Minimum	Maximum	Minimum	Maximum
Dense seagrass	4.46	5.05	5.07	5.35
Sparse seagrass	6.22	6.53	5.86	6.10
Sand	6.89	7.26	6.32	6.48
Dense *Montastraea* reef	3.80	**4.42**	4.76	**5.25**
Gorgonian plain	6.03	6.69	5.03	**5.50**
Lobophora dominated algal areas and coral patch reefs	See Table 8.3			

Activity: Return to your stacked set of two masked depth-invariant bottom-index images **Depth-invariant_masked#01.dat** and **Depth-invariant_masked#02.dat**. Open the Formula document **Classification1.frm**. Study the formula document to see how it works (see notes below).

Note that the CONST statements set up the maxima and minima for each habitat class, whilst the box-classifier statements check whether pixels in each of the two images lie within the box boundaries. If they do, it sets output image pixels to a value unique to that class (see Table 8.5), if they don't it sets output image pixels to 0. One output image is created per habitat class so each can be regarded as being like a layer in a Geographical Information System (GIS). If you add all the output images (layers) together then each habitat class will have a different pixel value and can be displayed as a different colour using an appropriate Palette document. Since some habitat classes overlap, a power of 2 series of pixel values has been chosen (Table 8.5) so that during addition one cannot create a valid pixel value for another class. Thus any pixel values in the image, which are not in the power series in Table 8.5, are unclassified because of falling into more than one class.

Table 8.5. Habitat classes used in classification with pixel values and colours assigned to each habitat by the formula and palette documents respectively.

Habitat class	Pixel value	Palette colour
Classified in more than one class (unclassified)	Not values below	Grey
Sand	32	Yellow
Sparse seagrass	16	Pale green
Gorgonian plain	8	Magenta
Lobophora dominated algal areas and coral patch reefs	4	Cyan
Dense seagrass	2	Dark green
Dense *Montastraea* reef	1	Khaki
Land or not classified in any class	0	Black

You will now try a classification based on the tight boxes in Figure 8.2 and the very limited number of training sites (field survey stations).

Activity: Make sure that the output images will be 8-bit unsigned integer images and that there will be <u>no</u> special handling of nulls, using the **Options!** menu available for Formula documents**.** Then **Copy** the Formula document *Classification1.frm* and **Paste** it to the connected images window. It will produce 6 images, one for each habitat class. [These will all look black as no pixels have values above 32. If you apply a stretch you should be able to see the patches of each habitat.] When the six images have been produced, minimize the stacked set of two masked depth-invariant images, close *Classification1.frm*, and minimize the *Depth-invariant_masked#01.dat* and *Depth-invariant_masked#02.dat* images. Then connect the 6 new images as a new stacked set. Finally, open a new Formula document and enter a formula to add all 6 images in the stack together.

Question: *8.7.* What is the simple formula that will add the six images together?

Activity: **Copy** this formula and **Paste** it to the stack of six images. Save the resultant image as *Classification1.gif* and the formula as *Add_6_layers.frm*. Then apply the palette *Classification.pal* (i.e. open and apply the palette while *Classification1.gif* is the active window). Close the stacked set of the six images and all six of the constituent habitat images without saving them.

Question: *8.8.* What is the primary problem with the resultant classified image (*Classification1.gif*)?

As mentioned earlier the limited number of training sites are unlikely to adequately represent the habitat classes. To see the effect of using more training sites, you will now classify the marine habitats using box-classifiers based on twice as many training sites.

Activity: Restore your stacked set of two masked depth-invariant bottom-index images *Depth-invariant_masked#01.dat* and *Depth-invariant_masked#02.dat*. Open the Formula document *Classification2.frm*. Study the formula document and note that some of the CONST statements use different maxima and minima. Also a "bespoke" box-classifier consisting of two boxes has been created for the gorgonian plain habitat. This should allow a better classification. Make sure that the output images will be 8-bit unsigned integer images with no special handling of nulls, using the Formula document **Options!** dialog box. Then apply the new formula to the stacked set of two images and wait until the six new (very dark if not stretched) habitat maps (GIS layers) have been created. Then close the *Depth-invariant_masked#01.dat* and *Depth-invariant_masked #02.dat* images and their stacked set, and close *Classification2.frm*.

Finally, as before, use **Image, Connect** to stack the 6 new images and then use your *Add_6_layers.frm* formula to add the 6 images together. Save the resultant image as *Classification2.gif* and apply the *Classification.pal* palette to it to display the different habitats.

Question: *8.9.* In what way has the habitat map improved with the extra field data?

Activity: Compare the two classifications and experiment with passing a 3x3 and 5x5 **Median** smoothing filter over the image to allow the broad distribution of the habitats to more clearly seen. When you have finished close all files. Do not save the 6 habitat images.

This lesson has demonstrated a very simple box-classification method. The box-classifier could be further refined to give better results. In reality more sophisticated classification methods, such as minimum distance to means and maximum likelihood classification, are used (see, for example, Mather, 1999: Chapter 8) but the principles remain the same. Training sites are used to establish how habitat classes are distributed in feature space, and pixels are then assigned to habitats on the basis of their position in feature space. For this lesson our feature space is only in two dimensions as shown in Figures 8.1 and 8.2 but it can be in three or more dimensions (one for each band used).

References

Green, E.P., Mumby, P.J., Edwards, A.J. and Clark, C.D. (Ed. A.J. Edwards) (2000). *Remote Sensing Handbook for Tropical Coastal Management. Coastal Management Sourcebooks 3.* UNESCO, Paris. ISBN 92-3-103736-6 (paperback).

Mather, P.M. 1999. *Computer Processing of Remotely-Sensed Images: an Introduction.* Second Edition. Wiley and Sons, Chichester, New York. 292 pp.

Appendix 8.1

Ground-truthing data from 7 training sites for each of 7 habitat classes.

Easting	Northing	TM_#1_#3	TM_#2_#3	Habitat
237117	2378610	4.889	5.074	dense seagrass
237434	2378308	5.050	5.354	dense seagrass
237552	2378205	4.889	5.074	dense seagrass
238546	2377947	4.698	5.224	dense seagrass
238572	2378124	4.971	5.254	dense seagrass
239496	2378272	4.461	5.165	dense seagrass
241581	2379096	4.698	5.074	dense seagrass
	Max	5.05	5.35	
	Min	4.46	5.07	
241286	2378559	6.319	6.072	sparse seagrass
239489	2378411	6.389	6.051	sparse seagrass
239040	2378316	6.431	6.098	sparse seagrass
239091	2378132	6.219	5.855	sparse seagrass
237544	2378051	6.529	5.902	sparse seagrass
237382	2378154	6.529	5.966	sparse seagrass
237176	2378235	6.277	5.888	sparse seagrass
	Max	6.53	6.10	
	Min	6.22	5.86	
235585	2377564	6.886	6.323	sand
235298	2378205	6.960	6.396	sand
231917	2376695	7.262	6.483	sand
230746	2378117	7.124	6.437	sand
235762	2380341	6.990	6.351	sand
241743	2381866	6.991	6.370	sand
242177	2382234	6.976	6.432	sand
	Max	7.26	6.48	
	Min	6.89	6.32	
242207	2380628	3.962	4.756	dense *Montastraea* reef
242192	2379616	3.962	5.030	dense *Montastraea* reef
242030	2382809	3.798	4.819	dense *Montastraea* reef
241846	2379428	4.068	5.123	dense *Montastraea* reef
241919	2379045	4.417	5.245	dense *Montastraea* reef
241536	2378743	4.889	5.354	dense *Montastraea* reef
241205	2378132	5.418	5.573	dense *Montastraea* reef
	Max	5.42	5.57	
	Min	3.80	4.76	

241809	2378330	6.693	5.816	Gorgonian plain
242538	2379096	6.031	5.030	Gorgonian plain
242847	2379781	6.031	5.421	Gorgonian plain
242833	2381019	6.176	5.361	Gorgonian plain
240247	2377756	6.666	5.491	Gorgonian plain
236896	2377233	6.228	5.245	Gorgonian plain
235445	2375834	6.228	5.245	Gorgonian plain
	Max	6.69	5.82	
	Min	6.03	5.03	
234716	2375289	6.122	5.670	*Lobophora*
235224	2375826	5.638	5.418	*Lobophora*
235453	2376224	6.070	5.666	*Lobophora*
236160	2377034	5.952	5.695	*Lobophora*
236918	2377395	5.916	5.603	*Lobophora*
239724	2378161	6.155	5.867	*Lobophora*
234392	2374876	5.463	5.485	*Lobophora*
	Max	6.16	5.87	
	Min	5.46	5.42	
233412	2376408	5.781	5.712	Coral patch reef
231919	2376445	6.101	5.701	Coral patch reef
242037	2382411	5.638	5.582	Coral patch reef
242295	2382124	6.122	5.666	Coral patch reef
241875	2381433	5.823	5.504	Coral patch reef
242111	2381306	5.188	5.469	Coral patch reef
238119	2377690	5.367	5.447	Coral patch reef
	Max	6.12	5.71	
	Min	5.19	5.45	

Appendix 8.2

The ***Classification1.frm*** formula document, which uses the Figure 8.2 boxes as a basis for classification.

```
# Formula document to classify a Landsat TM image of the shallow sea around South Caicos.
#
# This document uses two depth-invariant bottom index images:
# Depth-invariant_masked#01.dat (@1)
# and Depth-invariant_masked#02.dat (@2)
#
# Dense seagrass class boundaries
        CONST DenSeagMin1 = 4.46 ; CONST DenSeagMax1 = 5.05 ;
        CONST DenSeagMin2 = 5.07 ; CONST DenSeagMax2 = 5.35 ;

# Sparse seagrass class boundaries
        CONST SpSeagMin1 = 6.22 ;    CONST SpSeagMax1 = 6.53 ;
        CONST SpSeagMin2 = 5.86 ;    CONST SpSeagMax2 =6.10 ;

# Sand class boundaries
        CONST SandMin1 = 6.89 ; CONST SandMax1 = 7.26 ;
        CONST SandMin2 = 6.32 ; CONST SandMax2 = 6.48 ;

# Lobophora dominate algal area and coral patch reef class boundaries
        CONST LobCoralMin1 = 5.19 ; CONST LobCoralMax1 = 6.16 ;
        CONST LobCoralMin2 = 5.42 ; CONST LobCoralMax2 = 5.87 ;

# Dense Montastraea reef class boundaries
        CONST MontMin1 = 3.80 ; CONST MontMax1 = 4.42 ;
        CONST MontMin2 = 4.76 ; CONST MontMax2 = 5.25 ;

# Gorgonian plain class boundaries
        CONST GorgMin1 = 6.03 ; CONST GorgMax1 = 6.69 ;
        CONST GorgMin2 =5.03 ; CONST GorgMax2 =5.50 ;

# Sand box-classifier
        IF ( (@1 >= SandMin1) AND (@1 <= SandMax1) AND (@2 >= SandMin2) AND (@2 <=
SandMax2) ) 32  ELSE 0 ;

# Sparse seagrass box-classifier
        IF ( (@1 >= SpSeagMin1) AND (@1 <= SpSeagMax1) AND (@2 >= SpSeagMin2) AND (@2
<= SpSeagMax2) ) 16 ELSE 0 ;

# Gorgonian plain box-classifier
        IF ( (@1 >= GorgMin1) AND (@1 <=GorgMax1) AND (@2 >= GorgMin2) AND (@2 <=
GorgMax2) ) 8 ELSE 0 ;

# Lobophora dominated algal areas and coral patch reef  box-classifier
        IF ( (@1 >= LobCoralMin1) AND (@1 <= LobCoralMax1) AND (@2 >= LobCoralMin2) AND
(@2 <= LobCoralMax2) )  4 ELSE 0 ;

# Dense seagrass box-classifier
        IF ( (@1 >= DenSeagMin1) AND (@1 <= DenSeagMax1) AND (@2 >= DenSeagMin2) AND
(@2 <= DenSeagMax2) )  2 ELSE 0 ;

# Dense Montastraea reef box-classifier (sets this class to value of 1)
        IF ( (@1 >= MontMin1) AND (@1 <= MontMax1) AND (@2 >= MontMin2) AND (@2 <=
MontMax2) )  1 ELSE 0 ;
```