

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

Aim of Lesson

To undertake a 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 use UTM coordinate referenced field survey data of shallow water marine habitats and inspection of a Landsat TM image to derive spectral signatures for the major marine habitats (sand, seagrass, algae, gorgonian plain, coral reef).
3. To perform a simple box classification of marine habitats into sand, seagrass, algae, gorgonian plain, and coral reef in turn.
4. 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 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** (see Part 5 of the *Introduction*) to carry out mathematical manipulations of images. 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, radiometrically and atmospherically corrected (Lesson 3), and finally water column corrected (Lesson 5) to produce two depth-invariant bottom index bands; one from bands 1 and 3 (DI_TM13.DAT) and one from bands 2 and 3 (DI_TM23.DAT). The third depth-invariant band (from bands 1 and 2) will not be used here. The subscenes provided are of the South Caicos area only and are 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 image of the same area (TMBAND5.GIF).

Field survey data

You are provided with a spreadsheet (HABITATS.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 (DI_TM13.DAT and DI_TM23.DAT) are provided for most sites but you will be asked to collect the spectra for 2 sand and 2 sparse seagrass sites.

Lesson Outline

The first task is to mask out the land areas on the two depth-invariant bottom index images (DI_TM13.DAT and DI_TM23.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 best and to remove the distraction of terrestrial habitats which are best classified separately using a combination of infra-red and visible wavebands, we should mask out the land areas. This is easily achieved using a Landsat TM band 5 infra-red image (TMBAND5.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 for Windows* if you have not already done so. Open the two depth-invariant images (DI_TM13.DAT and DI_TM23.DAT) and the band 5 image (TMBAND5.GIF). Note the rather low contrast of the depth-invariant images even when contrast stretched. Connect the three images using the **Image, Connect** function. Use the connect toolbar to ensure that TMBAND5.GIF becomes image 1, DI_TM13.DAT becomes image 2, and DI_TM23.DAT becomes image 3.

The next step is to make a mask using TMBAND5.GIF. We want to produce an image from it with 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 TMBAND5.GIF image. Note that the sea pixels are uniformly dark whilst the land pixels are very variable. 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.

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, GoTo** 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: 6.1. What is the highest pixel value in areas which 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:

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

where @1 is the TMBAND5.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 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 file will be the same as @1 or 8-bit integer.

Copy the formula and **Paste** it to the connected images window where TMBAND5.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 TM_MASK6.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, the band 5 image TMBAND5.GIF, and the formula document (without saving any changes).

You now want 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** TM_MASK6.GIF with the two depth-invariant images and use the connect toolbar to make DI_TM13.DAT image 1, DI_TM23.DAT image 2, and TM_MASK6.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: 6.2. What two formula statements are required to make the two masked images?

When you are satisfied with your formula statements. 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 32 bit float images as DITM1.DAT (for the DI_TM13.DAT masked image) and DITM2.DAT (for the DI_TM23.DAT masked image). Close the connected images window, the TM_MASK6.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.XLS) to derive spectral signatures for major marine habitats and then use these signatures to classify the image. The classification method which will be tried is to create a simple box 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 which 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.XLS. This gives a listing of the training sites which will 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.

Make the DITM1.DAT image the active window. Use **Edit, GoTo** (with UTM check box set to on) to locate the relevant pixels which are listed in Table 6.1 for your convenience. The GoTo function puts you on the north-west corner of the pixel containing the GPS coordinates input. Enter the pixel values to **3 decimal places** in Table 6.1. When you have found the four sites on DITM1.DAT repeat the procedure for the DITM2.DAT image.

Table 6.1. Locate the pixels nearest to the GPS coordinates from the field survey and fill in the missing pixel values.

GPS coordinates		Depth-invariant bottom index bands		Habitat
Easting (X:)	Northing (Y:)	TM bands 1/3	TM bands 2/3	
237367	2378168			Sparse seagrass
237161	2378250			Sparse seagrass
241741	2381881			Sand
242162	2382248			Sand

Switch back to the HABITAT.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 6.2, 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 6.2 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 their 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 6.1. 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:*
- 6.3. Which two habitats are clearly separable from all other habitats?
 - 6.4. Which two habitats occupy very similar areas in feature space?
 - 6.5. Which two habitats are likely to be confused with dense *Montastraea* reef patches?
 - 6.6. With which two habitats is gorgonian plain likely to be confused?

Table 6.2. Minimum and maximum reflectances in depth-invariant bottom index images for 7 major marine habitats.

Habitat class	TM bands 1/3 depth-invariant		TM bands 2/3 depth-invariant	
	Minimum	Maximum	Minimum	Maximum
Dense seagrass				
Sparse seagrass				
Sand				
Dense <i>Montastraea</i> reef				
Gorgonian plain				
<i>Lobophora</i> 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 6.3.

Table 6.3. 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
<i>Lobophora</i> dominated algal areas and coral patch reefs				

This improves the classification scheme but two further anomalies need addressing. As is evident from Figure 6.1 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 6.2). 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 6.2 are listed below in Table 6.4.

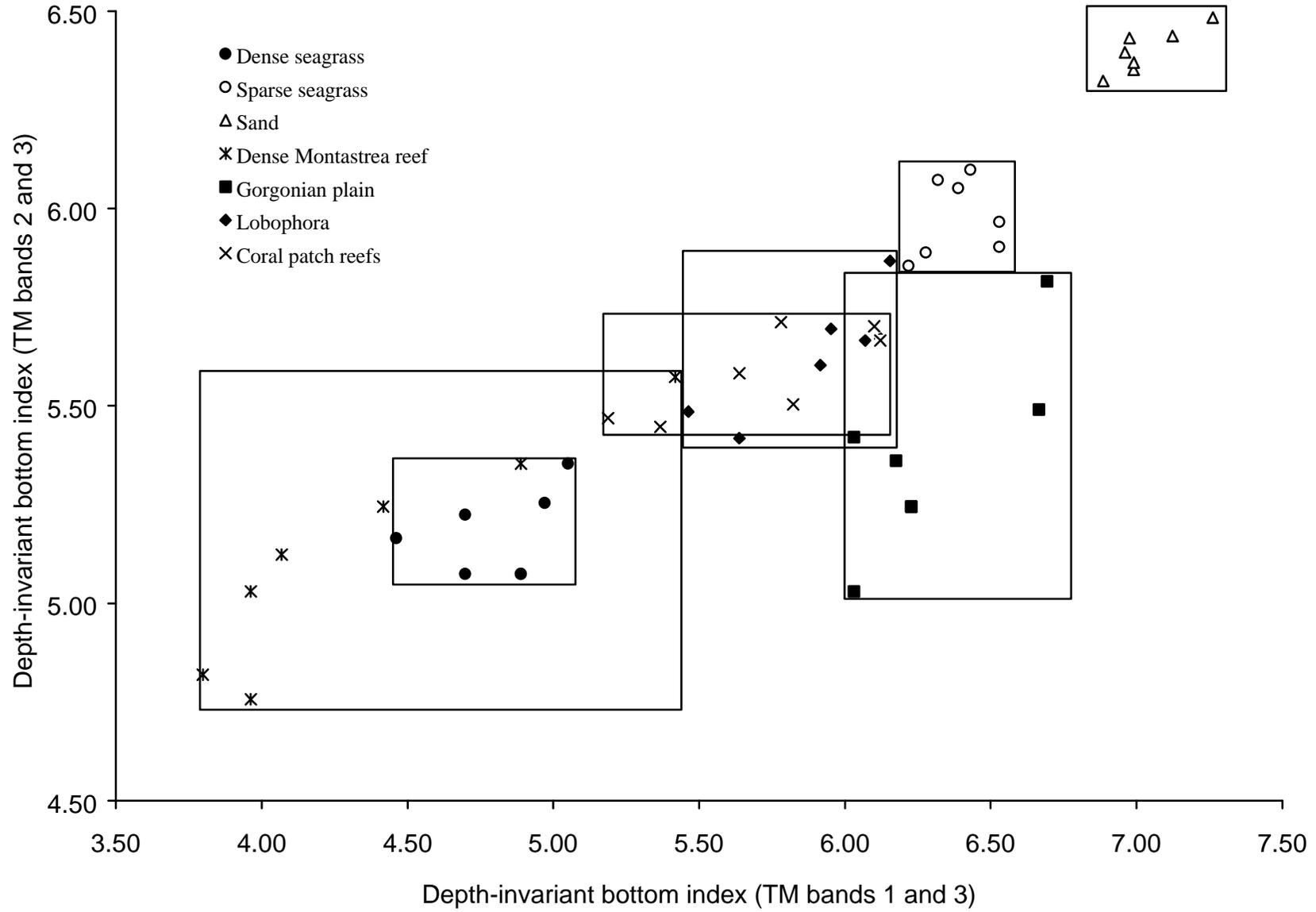
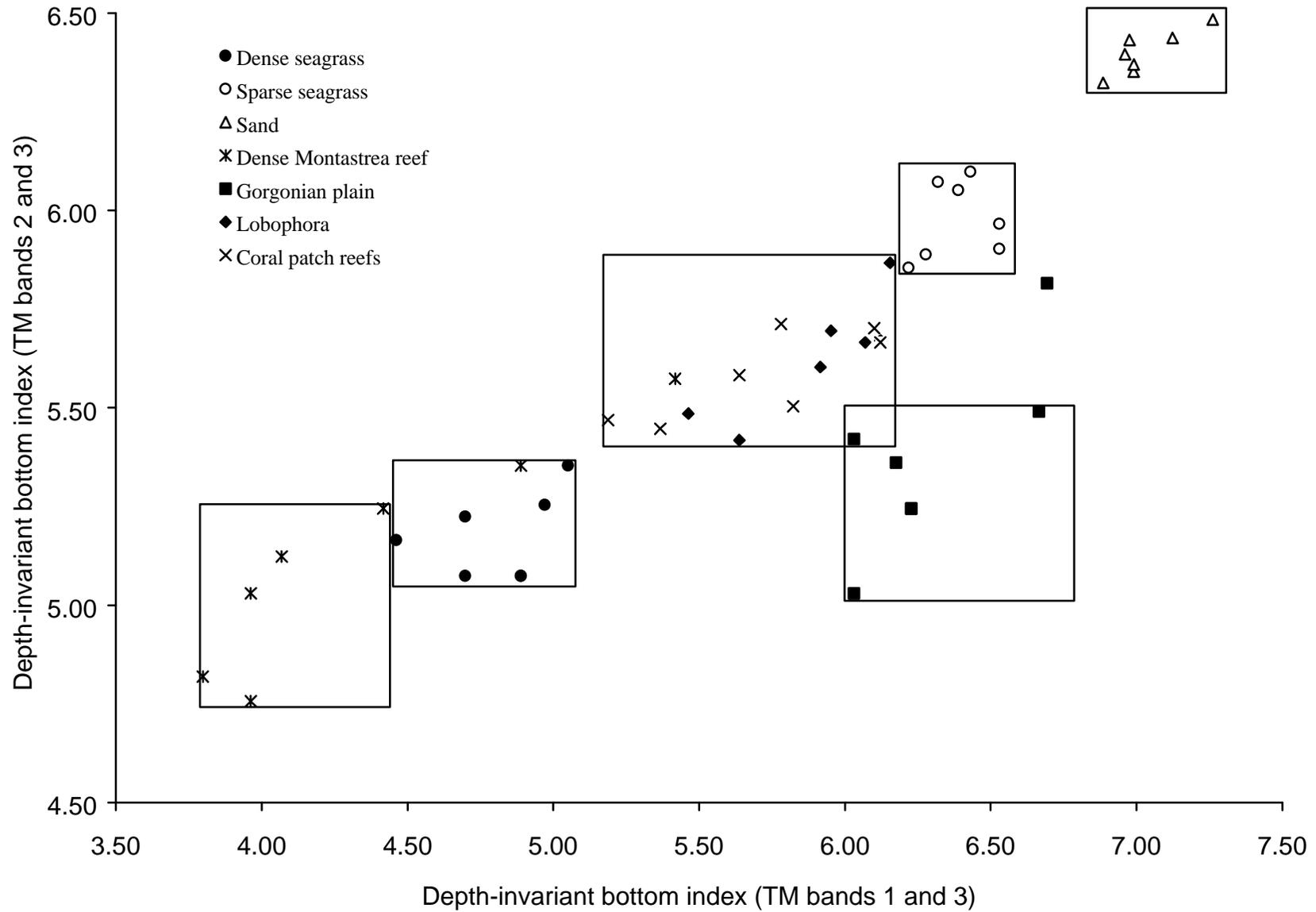


Figure 6.2. Box-classification where *Lobophora* and coral patch reef classes are merged, some gorgonian plain is left unclassified, and some dense *Montastraea* reef class is mis-classified as dense seagrass or a coral patch reef/*Lobophora*. However, this scheme is likely to produce a better map than Figure 6.1.



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 6.4. Minimum and maximum reflectances in depth-invariant bottom index images for 6 major marine habitats, using box-classifiers illustrated in Figure 6.2. 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 <i>Montastraea</i> reef	3.80	4.42	4.76	5.25
Gorgonian plain	6.03	6.69	5.03	5.50
<i>Lobophora</i> dominated algal areas and coral patch reefs	See Table 6.3			

Activity: **Connect** the two masked depth-invariant bottom-index images DITM1.DAT and DITM2.DAT. Open the Formula document CLASSIF1.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 6.5), 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 6.5) 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 6.5 are unclassified because of falling into more than one class.

Table 6.5. 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
<i>Lobophora</i> dominated algal areas and coral patch reefs	4	Cyan
Dense seagrass	2	Dark green
Dense <i>Montastraea</i> 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 6.2 and the very limited number of training sites (field survey stations).

Activity: Make sure that the output images will be **8-bit integer images** using the **Options!** menu available for Formula documents. Then **Copy** the Formula document CLASSIF1.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, close the connected images window, close CLASSIF1.FRM, and minimize the DITM1.DAT and DITM2.DAT images. Then connect the 6 new images and make them 1 to 6 on the connect toolbar. Finally, open a new Formula document and enter a formula to add all 6 images together.

Question: 6.7. What is the simple formula which will add the six images together?

Copy this formula and **Paste** it to the connected images window. Save the resultant image as CLASSIF1.GIF and the formula as ADD6.FRM. Then apply the palette CLASSIF1.PAL (i.e. open and apply the palette while CLASSIF1.GIF is the active window). Close the connected images window and all six of the habitat images without saving them.

Question: 6.8. What is the primary problem with the resultant image?

As mentioned earlier the limited number of training sites may not 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.

Connect the DITM1.DAT and DITM2.DAT images, making DITM1.DAT image 1, and DITM2.DAT image 2 with the connect toolbar. Open the Formula document CLASSIF2.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 integer images** using the Formula document **Options!** menu. Then apply the new formula to the connected images window and wait until the six new (very dark if not stretched) habitat maps (GIS layers) have been created. Then close the connected images window, close CLASSIF2.FRM, and minimize the DITM1.DAT and DITM2.DAT images.

Finally, as before, add the 6 images together. Save the resultant image as CLASSIF2.GIF and apply the CLASSIF1.PAL palette to it to show up the different habitats.

Question: 6.9. In what way has the habitat map improved with the extra field data?

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 are used (see, for example, Mather, 1987: Chapter 8) but the principle remains the same. Training sites are used to establish how habitat classes are distributed in feature space, and pixels are then be 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 6.1 and 6.2 but it can be in three or more.

References

Mather, P.M. 1987. *Computer Processing of Remotely-Sensed Images: an Introduction*. Wiley and Sons, Chichester, New York. 352 pp.

Answers to Questions

- 6.1. The highest pixel value in both blocks is 7. Thus pixels with values above 7 can be considered as being land.
- 6.2. On line one you should have @1 * @3 ; On line two you should have @2 * @3 ;
- 6.3. Sand and sparse seagrass have clear non-overlapping boxes and are thus clearly separable from all other habitats.
- 6.4. Coral patch reefs and *Lobophora* dominated algal areas occupy very similar areas in feature space for these two depth-invariant bands and are hopelessly confused spectrally. The dense seagrass category is contained within the dense *Montastraea* reef parallelepiped, although the majority of pixels in each class cluster in different parts of feature space.
- 6.5. There is overlap between dense *Montastraea* reef areas and both dense seagrass and coral patch reef habitats.
- 6.6. Because of the outlier with a relatively high depth-invariant bottom index value in TM band2_3, gorgonian plain is likely to be confused with both *Lobophora* dominated algal areas and coral patch reefs.

Table 6.1. The values of the pixels nearest to the GPS coordinates obtained during the field survey.

GPS coordinates		Depth-invariant bottom index bands		
Easting (X:)	Northing (Y:)	TM bands 1/3	TM bands 2/3	Habitat
237367	2378168	6.529	5.966	Sparse seagrass
237161	2378250	6.277	5.888	Sparse seagrass
241741	2381881	6.991	6.370	Sand
242162	2382248	6.976	6.432	Sand

Table 6.2. Minimum and maximum reflectances in depth-invariant bottom index images for 7 major marine habitats.

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 <i>Montastraea</i> reef	3.80	5.42	4.76	5.57
Gorgonian plain	6.03	6.69	5.03	5.82
<i>Lobophora</i> dominated algal areas	5.46	6.16	5.42	5.87
Coral patch reef	5.19	6.12	5.45	5.71

Table 6.3. 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
<i>Lobophora</i> dominated algal areas and coral patch reefs	5.19	6.16	5.42	5.87

6.7. @1 + @2 + @3 + @4 + @5 + @6 ;

6.8. The main problem with the CLASSIF1.GIF file is that too much of the submerged area is unclassified. Given the broad classes involved which include most of the habitats likely to be encountered, this suggests that the training sites do not adequately represent the habitat classes in question. Also areas of water on land such as the salinas classify as various marine habitats as they have similar pixel values.

6.9. Much more of the submerged habitats are classified as the greater number of training sites has better sampled the spread in feature space for each habitat.

Appendix 6.1

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

Easting	Northing	TM_13	TM_23	Habitat
237102	2378625	4.889	5.074	dense seagrass
237419	2378323	5.050	5.354	dense seagrass
237537	2378220	4.889	5.074	dense seagrass
238531	2377962	4.698	5.224	dense seagrass
238557	2378139	4.971	5.254	dense seagrass
239481	2378287	4.461	5.165	dense seagrass
241566	2379111	4.698	5.074	dense seagrass
	Max	5.05	5.35	
	Min	4.46	5.07	
241271	2378574	6.319	6.072	sparse seagrass
239474	2378426	6.389	6.051	sparse seagrass
239025	2378331	6.431	6.098	sparse seagrass
239076	2378147	6.219	5.855	sparse seagrass
237529	2378066	6.529	5.902	sparse seagrass
237367	2378168	6.529	5.966	sparse seagrass
237161	2378250	6.277	5.888	sparse seagrass
	Max	6.53	6.10	
	Min	6.22	5.86	
235570	2377579	6.886	6.323	sand
235283	2378220	6.960	6.396	sand
231902	2376710	7.262	6.483	sand
230731	2378132	7.124	6.437	sand
235747	2380356	6.990	6.351	sand
241741	2381881	6.991	6.370	sand
242162	2382248	6.976	6.432	sand
	Max	7.26	6.48	
	Min	6.89	6.32	
242192	2380643	3.962	4.756	dense <i>Montastraea</i> reef
242177	2379631	3.962	5.030	dense <i>Montastraea</i> reef
242015	2382824	3.798	4.819	dense <i>Montastraea</i> reef
241831	2379443	4.068	5.123	dense <i>Montastraea</i> reef
241904	2379060	4.417	5.245	dense <i>Montastraea</i> reef
241521	2378758	4.889	5.354	dense <i>Montastraea</i> reef
241190	2378147	5.418	5.573	dense <i>Montastraea</i> reef
	Max	5.42	5.57	
	Min	3.80	4.76	

241794	2378345	6.693	5.816	Gorgonian plain
242523	2379111	6.031	5.030	Gorgonian plain
242832	2379796	6.031	5.421	Gorgonian plain
242818	2381034	6.176	5.361	Gorgonian plain
240232	2377771	6.666	5.491	Gorgonian plain
236881	2377248	6.228	5.245	Gorgonian plain
235430	2375849	6.228	5.245	Gorgonian plain
	Max	6.69	5.82	
	Min	6.03	5.03	
234701	2375304	6.122	5.670	<i>Lobophora</i>
235209	2375841	5.638	5.418	<i>Lobophora</i>
235438	2376239	6.070	5.666	<i>Lobophora</i>
236145	2377049	5.952	5.695	<i>Lobophora</i>
236903	2377410	5.916	5.603	<i>Lobophora</i>
239709	2378176	6.155	5.867	<i>Lobophora</i>
234377	2374891	5.463	5.485	<i>Lobophora</i>
	Max	6.16	5.87	
	Min	5.46	5.42	
233397	2376423	5.781	5.712	Coral patch reef
231904	2376460	6.101	5.701	Coral patch reef
242022	2382426	5.638	5.582	Coral patch reef
242280	2382139	6.122	5.666	Coral patch reef
241860	2381448	5.823	5.504	Coral patch reef
242096	2381321	5.188	5.469	Coral patch reef
238104	2377705	5.367	5.447	Coral patch reef
	Max	6.12	5.71	
	Min	5.19	5.45	

Appendix 6.2

The CLASSIF1.FRM formula document which uses the Figure 6.2 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 DITM1.DAT (@1)
# and DITM2.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 ;
```