PN-AAW-267
47968

FINAL REPORT

Mangrove Forest Assessment and Mapping with Aerial Photographs and Landsat Digital MSS Data in Aguadulce and Chame, Panama.

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February 1985.

1.0 SUMMARY

The objective of the study was to analyze existing black-and-white aerial photographs for the assessment and mapping of mangrove forests in two critically disturbed study sites in the Republic of Panama. Basic field research data on the ecosystem of each study site were collected through field observations and measurements at pre-selected sample plots, and were then associated with photo pacterns during the image interpretation phase of the project. Also identified on the photographs were principal sources of stress and human disturbances, such as timber harvesting, charcoal production, aquaculture ponds, and encroachment of adyacent land use types.

The approach required the interpretation of two sets of photographs for each study site, using imagery acquired in the mid-1960's and the early 1980's. Photographs for each date were classified and compared to detect and map the change over time occurring in the study areas. The classification scheme was based upon field measurements of species, basal area, density, and forest development or structure. Areal measurements were made of each classified photograph using a polar planimeter.

The results included statistical summaries of the aereal measurements of each mapping unit and transparent overlays of each classified photograph Based upon an analysis of the statistical results and the thematic maps, the following conclusions were indicated. (1) black-and-white aerial photography provided an effective method for mangrove forest assessment; (2) this method serves as a useful tool for management of mangrove forest; (3) the classification scheme provided a meaningful and fairly accurate method for mangrove forest assessment in the two study sites.

2.0 INTRODUCTION

The principle objective of this project is to utilize existing black-and-white aerial photographs and Landsat MSG digital imagery to survey and quantitively map the nature and distribution of mangrove vegetation in two critically disturbed study sited in the Republic of Panama. Products derived from the image analysis will be used to assist in the development of a national mangrove resource management plan. Aerial photography for the mid-1960's and the 1980s was interpreted using conventional (visual) techniques. The single Landsat image was processed using digital analysis techniques.

The imagery used in the analysis was selected to span a 15 to 20 year period to provide pre-development base-line information about mangrove forest structure, and to detect changes taking place in the forest over time. A primary goal of the remote sensing environmental analysis is to locate and identify principal sources of stress and human disturbances such as the direct exploitation of mangrove resources by encroachment of adjacent land use types and timber harvesting, for example.

Direct field observations in support of the remote sensing analysis were made to provide basic research data related to the ecosystem of each study site. Field measurements of tree height, density (or stocking level), and basal area were related to information classes used in the analysis to generate quantitative descriptions of the forest structure.

3.0 STUDY SITES

The two study areas developed as part of this study were located on the Pacific coast of Panama west of the capital city. Both areas are being subjected to ever-increasing exploitation ranging from direct harvesting to encroachment by mariculture industries such as shrimp farming. A brief description of each site follows:

Chame: This mangrove forest fringing Chame Bay is located about 30 air miles west of Panama City near the recreational development known as Punta Chame, and can be reached by car from the capitol in just over an hour. The forest is being intensively exploited for timber and charcoal production, and since 1980 many hectares of shrimp ponds have been established. The area considered in the study includes the entire forest area at Chame with the exception of the eastern shore of the estuary which lacked adequate stereo air photo coverage.

Aguadulce: The actual mangrove forest studied was located along the Rio Grnade which flows into the Gulf of Parita. The eastern boundary was taken to be the Rio Estancia. The western boundary was held approximately at the Estero Palo Blanco. The entire coastline of the Gulf of Parita is fringed with well-developed mangrove forest and presented a problem only in that a practical limit had to be placed on the size and location of the study area. The forest of the site selected is the most extensive and is well-developed and easily accessible by small boat. Like the forest at Chame, widespread exploitation is evident. Extensive shrimp ponds have also been constructed in the area. The town of Penonome was used as a base for the study, and can be reached from Panama City in two hours by car.

4.0 ACQUISITION OF IMAGERY

The two principle types of imagery acquired for the project were black-and-white panchromatic aerial photograhs and a Landsat-2 MSS image. Photographs were obtained for two dates for each study site. The photos were originally flown to provide coverage for topographic mapping projects undertaken by the Instituto Geográfico National "Tommy Guardia". Complete stereo coverage (60% overlap, 30% sidelap) exists for both areas for both dates, with the single exception of the eastern fringe of the Chame site. The Landsat scene was acquired by the satellite in January 1979 and contains complete data for each study site. The identification number of the Landsat image is E-21459-14465. All imagery was provided courtesy of the DMA-IAGS Cartographic School in Fort Clayton, Panama.

As is always the case with existing imagery, the user must accept what is available and therefore has no control of the quality of the photographs over the site of interest. In all cases for this project, the quality of the photos was acceptable but some clouds were present in the study area. Clouds are a persistent problem in Panama and cloud-free images (especially from satellites) are difficult to obtain. Also, for a project of this nature which demands detailed information about vegetation, panchromatic photography may not be the best choice, and other film and filter combinations should be considered. Even more important is the photo scale, which unfortunately was smaller than desired. The smallest scale recommended for any future detailed study of mangrove vegetation would be 1:15,000.

The Landsat-2 image was acquired from the EROS Data Center in Sioux Falls, South Dakota in the form of a Computer Compatible Tape, or CCT. Each scene represents an area of approximately 185 kilometers by 185 kilometers. Resolution of individual picture elements (or pixels) in the original image is 56 meters by 79 meters, and consists of four channels of information. Clouds are widely distributed in the image, but are sparse in the Chame zone and nonexistent in the Aguadulce site.

4.1 CHAME

The 1965 photography for Chame was flown on 6 January 1965 at the scale of 1:20,000. Large expanses of mudflats and sand beaches indicate a low tide condition during the photo mission. Some clouds (and their corresponding shadows) are visible over the study area. A few of the photos exhibit rather poor contrast, especially for vegetated areas.

The 1982 photos were flown during the month of January. Extensive mudflats and sandbars are visible in the photos. Clouds and shadows conceal some areas of the image from stereo viewing. Overall contrast of the photos is good. The scale of the photography is 1:30,000.

4.2 AGUADULCE

The photography for 1965 was flown on the 25th of December. Photo scale is 1:16,600. There are no tidal flats visible. The entire area is cloud-free. Although some of the photos have poor contrast, the problem can probably be attibuted to processing and development of the prints.

The 1980 imagery was acquired during January at a scale of 1:40,000. No clouds are visible and contrast is good. No tidal flats or sandbars are visible.

5.0 FIELD OBSERVATIONS

Field observations were designed for a three-fold purpose: (1) to visit on a stratum-by-stratum basis representative areas on the ground to compare surface conditions with corresponding photographic images, (2) to collect type, density, and size data about vegetation characteristics at selected locations, and (3) to assess human disturbances and activities related to resource exploitation.

The limited scope and resources of the project coupled with rather stringent time constraints on the participants prevented the acquisition of sufficient field data to project with any certainty the volume and growth characteristics of the forest based on the classification system. Detailed field observations were made at numerous sites in both Chame and Aguadulce, however, and where possible these measurements were related directly to the stratification classes. The data presented in Table 1 for Chame and Table 2 for Aguadulce.

Several methods were used to assess the characteristics of the forest. The techniques evolved as the result of unfavorable initial experiences in the field, and unsatisfactory measurement techniques. The methods used for collecting field observations follow in the order they were applied:

5.1 Quadrant method

The quadrant method was initially selected but it provided poor results, probably due to the heterogeneity of the mangrove forest of Chame, which includes medium and low density areas, dwarf mangroves, and heavily harvested areas.

5.2 Fixed area plots

Random fixed area plots of 100 square meters were attempted and the results of this method seem suitable for the project scope. However, if all the trees within the plots are measured, the method become very time consuming and labor intensive.

5.3 Point Sampling

The estimation of basal area and density using the optical instrument called a Reloskop seems to be the best in the alternatives and after testing this method in the field it was adopted for all additional field observations. In this method, an observer stands at one point and makes a sweep of the surrounding trees, counting all the trees which have a diameter at breast height (DBH) larger than the selected optical band of the instrument. Each band has a corresponding factor and the basal area is calculated by multiplying the number of trees counted by the factor. This sampling represents a correctly weighted sample, with more importance assigned to large trees and fewer small trees being represented.

6.0 PHOTO INTERPRETAION AND DIGITAL IMAGE PROCESSING

6.1 Photo Interpretation

Prior to actual interpretation activities, a photo mosaic was assembled for each study site using the imagery available for both dates. The mosaics were constructed using alternate photos along each flight line. Once completed the mosaic were phtographed at as 1:1 scale with a copy camera, producing on a single photographic print the entire mosaic at original scale. Stereo viewing of the entire mosaic was made possible by placing photos not used in mosaic construction over the mosaic and orienting the photos to create 3-dimensional models. The mosaice proved to be useful not only during the interpretation process but especially during field trips, when they could conveniently be viewed in stereo during training site selection.

The alternate photos used in the mosaic were the ones chosen for interpretation. To prevent duplication of effort in areas of overlap and sidelap on the photos, an effective area was marked on each photo by locating and marking common points on each photo. Lines were then drawn on each photo to indicate the boundary of the effective area, and the limits of the classification. This procedure was also helpful in reducing the use of the border areas of the photos.

Every photo to be classified was covered with a sheet of stable transparent acetate, which was fixed to the photo scale by taping the edges. Fiducial marks and necessary annotation were then drawn in ink on the acetate to register the overlays permanently to the photos.

Actual photo interpretation was accomplished by viewing in stereo each photo to be classified. Three different stereo-viewing instruments were used: a Wild APT-1 with dual optics, a mirror stereoscope, and a simple pocket stereoscope.

The initial classification scheme designed for this project was based on vegetation density, crown diameter, and tree height, and included a standard land use classificatin for areas adjacent to the mangrove forest. This system was judged inadequate for project objectives by the Mangrove Ecologist (Cintron, personal communication, 1984) and was replaced by a system he provided. The system is shown in Table 3. Adjacent land use types were not part of the classification as recommended. Using the system as a key, relatively homogeneous forest stands with regard to type, density, and size characteristics were completely delineated on the photographs. This stratification procedure was followed for both study areas and for both dates.

Height measurements of the forest cover were made using a Fairchild Stereocomparagraph. The instrument is used as follows: while viewing a stereo model, the fused image of two index marks can be brought into contact with a point of interest, in this case either the ground of the forest canopy. Difference in elevation (or height) between two points is represented as a difference in parallax, which is measured by a micrometer attached to one of the index marks. By using the measured differential parallax between two points, the difference in elevation (and therefore the height of a tree) can be computed using the basic differential parallax equation expressed as follows:

$$dP = bh/(H-h)$$

Where:

dP = measured differential parallax

b = photo air base

h = elevation of object above MSL

H = height of camera

Heights were measured on a stratum-by-stratum basis at numerous points throughout the study areas. The measurements were used as a check for classification accuracy with respect to tree size, and were most useful for training the analyst to recognize tree height during the stratification process. In areas of dense forest, it was nearly impossible to find a point visible on the ground surface which could be measured with the floating dot.

6.2 Digital Image Processing

Image processing was accomplished at the DMA-IAGS Cartographic School using an ERDAS/400 Digital Image Analysis System. The system consists of a Z-80 based microcomputer with 64K bytes of memory, dual 8-inch floppy disk drives, an interactive color display, a video terminal, a dot-matrix printer, and a tape drive.

Subsets of the Landsat scene covering each study site were transferred from the original CCT to a floppy dish for processing on the ERDAS system. Each of these subsets was viewed on the color monitor to insure completeness of data. Prior to the digital classification of the imagery, each subset of the image was geometrically corrected and registered precisely to a 1:50,000

scale topographic map. The coordinates for each pixel in the Landsat system (scan line and element) were transformed to UTM coordinates with the following linear transformation equations:

(1) x pixel = a1 * x map + a2 * y map + a3

(2) y pixel = b1 * x map + b2 * y map + b3.

The transformation matrix coefficients were computed by a least squares regression technique which used Ground Control Point (GCP's) located on the Landsat data and on the reference map. The GCP's were selected while interactively viewing the Landsat data on the color monitor and the map. Points such as road intersections and river confluences which could be uniquely identified on both the map and the Landsat data were chosen as GCP's.

The Landsat coordinates for each point were obtained by placing a moveable cursor on the appropriate pixel and reading the coordinates at the operator console. The UTM coordinates were scaled from the reference map.

The rectification of the Landsat data to the reference UTM grid required a rotation and pixel resampling. A nearest neighbor algorithm was used to resample image pixels to a 50 by 50 meter format.

The image subsets representing each study site were then classified using an unsupervised classifier (or clustering algorithm). This technique required a minimum of operator input, and assumed no "a priori" knowledge of the surface cover. The classifier processes the Landsat data in a two-pass

mode. During the first pass through the data, the classifier builds clusters (groups of points in spectral space) which represent statistically generated training fields. After all pixels in the image have been processed, the classifier begins the second pass and assigns all pixels to the appropriate cluster using a minimum distance algorithm.

The Landsat data for each site was classified into 27 clusters or classes. Since a clustering algorithm separates classes based solely upon differences in spectral signatures, the forest cover types represented by the output classes were unknown. The interpretation of each class with respect to a cover type was accomplished using the image overlay capability of the system. The original Landsat image was displayed on the color monitor and one by one the output classes were superimposed on the display. The spectral signatures of the output classes were used in the interpretation process, as were the classified photos.

7.0 PRODUCTION OF MAPS AND STATISTICS

The production of maps was accomplished in two separate phases, with distinct products being generated from the aerial photos and from the Landsat image.

7.1 Maps Derived from Aerial Photographs

Each classified photo was digitized on a Computer Automated Graphics System (CAGS).

The CAGS is an interactive graphic computer used at the Cartographic School for basic instruction of automated cartography. It consists of 5 workstations, 14 peripheral terminals, one ink pen plotter, and PDP-1170 Central Processing Unit. The actual work station of the CAGS consists of 2 CRTs, an electromagnetic x-y grid light table, a keyboard, and a digitizing cursor.

Several graphic files of the study area were established on the CAGS by digitizing topographic maps and overlays of classified aerial photographs. Topographic maps were registered to the grid light table as a controlled base map. Overlays of classified mangrove forest made from aerial photography were then referenced to the registered control base map by common x, y coordinates. This provided a means to rectify overlay data and produce a controlled map. Special routines were designed to modify basic CAGS functions so that project data digitized on the grid light table would result in graphical output as well as statistical tables of areal measurements according to mangrove forest classification.

Complications with hardware and modified software resulted in untimely delays and final abandonment of these methods. Shutdowns at the work station abortion of the programs, and loss of data were frequent problems. The specially designed software proved unsuitable for use in a production situation of this type, and statistical output was incomplete due to counter problems in the software.

Although several partial maps of each study area were produced, the technique and results were judged unacceptable.

Final measurements were made using a polar planimeter. Tables 4 and 5 show the computer number of hectares for each habitat type as classified on the photographs directly.

7.2 Maps Derived from the Landsat Image

Symbol maps for each classification were produced directly with the ERDAS/400 system using symbols designed for this project. In addition to the maps produced on the dot-matrix printer, statistics for each mapping unit were also calculated. Symbol maps for Chame and Aguadulce are shown in Figures 1 and 2, respectively. Cover type areas are shown in Tables 6 and 7.

8.0 RESULTS AND DISCUSSIONS

8.1 Field Observations

* substantial recent change in land cover not represented in the latest photos available.
* field sampling impractical in some areas due to inaccessibility.
* mangrove destruction is evident near shrimp pond facilities.
* dominant species in Chame and Aguadulce is "Rhizophora"
* exploitation activities in Chame and Aguadulce include charcoal, timber, shrimp ponds.

8.2 Photo Interpretation

* Scale of 1:16,600 or larger is preferred.
* Time of year of photos may be significant.
* Some confusion is evident between dense stands of "Avicennia" and immature "Rhizophera" based on photo tones and texture.
* Height measurements on the photos are difficult in areas of dense foliage.
* Photo quality was not consistent.

8.3 Digital Image Analysis

* Spectral measurements of mangrove vegetation are essential.
* Landsat-2 resolution (spectral and spatial) is insufficient for species differentiation.
* Future Repetitive Landsat coverage may be a problem.

8.4 Digitizing and Map Production

* Next step is Geographic Information System.

9.0 CONCLUSIONS AND RECOMMENDATIONS

* Special photo acquisition missions are suggested using different film/filter combinations and a larger scale.

* Geographical Information System should be established for mangrove study areas.
* Detailed stratum-by-stratum field sampling recommended.
* Up-to-date photos essential.
* Formal request for Landsat-5 acquisition should be made by AID.

TABLE 1. CHARACTERISTICS OF THE CHAME MANGROVE FOREST

Station No.	Canopy Height (m)	Basal Area (m^2/h)	Density stem/ha	% Diameter Distribution 0-5 cm	5.1-10 cm	10.1-15cm	>15 cm	Mapping Unit
1		14.05	5300	50.94%	32.07%	1.89%	.....	R2
2	10	13.11	3200	50.0 %	28.12%	3.12%	3.12%	R2
3		9.24	1705	52.94%	17.65%	23.53%	5.88%	R2
4	8.0	13.91	4238	16.67%	70.83%	12.5 %	.....	R3/L2
5	12	19.86	2274					R2
6	2	17.99	22333	95.52%	4.41%	.....	.....	Pinuelo
7	10	12.50	2200	9.09%	77.27%	13.64%	.....	R2
8	12	25.04	2500	24.0 %	32.0 %	32 %	12 %	R2
9	3	22.41	52222	63.83%	.....	2.13%	34.04%	R2
10	12	34.63	1000	10 %	10 %	50 %	30 %	A2
11	8	27.11	1400	49.99%	7.14%	21.42%	21.42%	R2
12	15	13.66	1700	5.88%	58.82%	29.41%	5.88%	R2
13	12	6.75	226	.....	37.5 %	.....	62.50%	R2
14	11	16.00	1593	.....	70 %	10 %	2 %	R2

TABLE 2. CHARACTERISTICS OF THE AGUADULCE MANGROVE FOREST

Station No.	Canopy Height (m)	Basal Area (m^2/h)	Density stem/ha	% Diameter Distribution				Mapping Unit
				0-5 cm	5.1-10 cm	10.1-15cm	>15 cm	
2	12.0	22.0	1580	.....	34.56%	.....	65.44%	A1
3	10.5	25.0	2552	.....	58.46%	27.70%	13.83%	A1
4	15.0	18.5	446	.....	.....	5.53%	94.43%	A1
5	15.0	24.0	1121	.....	56.91%	19.67%	23.41%	R2a
6	14.5	30.0	489	.....	.....	42.74%	57.34%	A1
7	12.5	16.0	270	.....	.....	16.63%	83.70%	R2a
8	12.5	30.0	818	.....	.....	28.24%	71.76%	A1
9	10.0	33.0	1682	.....	28.01%	35.18%	36.84%	A1
10	26.0	26.0	648	.....	30.71%	.....	69.29%	R1a
11	14.5	18.0	224	.....	.....	15.62%	84.38%	R2/A1
12	15.0	27.0	457	.....	.....	.....	100.0%	R2/A1

TABLE 3

MANGROVE CLASSIFICATION SYSTEM

Mapping Unit	Symbol	Descriptors and Qualifiers: Height class (m)	Symbol	Coverage (%)	Symbol
1. RHIZOPHERA	R	Tall (>20)	1	Continuous (70-100)	a
		Medium (10-20)	2	Interrupted (40-70)	b
		Low (5-10)	3	Sparse (10-40)	c
		Scrub (2-5)	4	Rare (<10)	d
		Dwarf (<2)	5		
2. AVICENNIA	A	Tall (10-20)	1		
		Medium (5-10)	2		
3. LAGUNCULARIA	L	Scrub (1-5)	3		
		Dwarf (<1)	4		
4. Salt flats	Sf	Efflorescent	1		
		Vegetated	2		
5. Mud flats	Mf				
6. Grass Lands (Supra Tidal)	Gs				
7. Sandy areas	Sb				
8. High ground	Hg				
9. Shrimp ponds	Sp				
10. Open water	W				
11. Unclassified	Uc				
12. Transportation	Tr.				

TABLE 4. AREA (HECTARES) OF COVER TYPES IN THE CHAME STUDY AREA, PANAMA

COVER TYPE(A)	1965 HECTARES	1982 HECTARES
R2a	1164.4	2312.1
R2b	2189.6	1201.5
R2c	25.6	63.0
R3a	220.4	66.6
R3b	310.0	97.2
R3c	591.2	77.4
R3d	21.2	-0-
R4b	23.2	25.2
R4c	122.0	46.8
R4d	57.6	-0-
R5c	26.4	20.7
A1a	142.0	14.4
A1b	16.8	-0-
A2a	464.0	218.7
A2b	46.4	5.4
A3a	398.0	368.1
A3b	176.8	140.4
A3c	32.0	-0-
A4a	20.4	19.8
A4b	11.2	11.7
A4c	70.0	95.4
A4d	59.6	18.9
Sf1	337.6	345.6
Sf2	30.4	44.1
Sb	6.4	26.1
Gs	169.2	81.9
Sp	-0-	303.3
Mf	-0-	52.2
TOTAL	6732.4	5656.5

(A) DESCRIPTORS BASED ON CINTRON (1984)

TABLE 5. AREA (HECTARES) OF COVER TYPES IN THE AGUADULCE STUDY AREA, PANAMA

COVER TYPE(A)	1965 HECTARES	1982 HECTARES
R1a	1941.0	2552.1
R1b	9.2	12.4
R1c	9.2	-0-
R2a	154.8	19.7
R2b	48.7	38.4
R2c	30.3	-0-
R3a	1.8	-0-
A1a	416.5	147.9
A1b	4.6	-0-
A2a	782.7	496.4
A2b	124.8	182.3
A2c	64.9	127.7
A3a	349.1	171.0
A3b	234.7	184.3
A3c	109.2	118.2
A3d	11.3	-0-
A4a	173.8	-0-
A4b	105.9	16.0
A4c	78.0	56.4
A4d	94.9	84.3
L2a	2.4	-0-
L3a	44.4	12.3
Sf1	72.8	93.9
Sf2	193.0	95.8
Sb	48.0	48.9
Gs	70.7	-0-
TOTAL	5176.7	4458.0

(A) DESCRIPTORS BASED ON CINTRON (1984)

Histogram listing for file CHAME2

This image has 281 ROWS . 241 COLUMNS

This is a GIS data file
The VARIABLE name is MANGROVE FOREST OF CHAME

DATA VALUE	NUMBER OF POINTS	NUMBER OF HECTARES	%	DESCRIPTION
0	6160.	1540.000	0.00 %	BORDER
1	18566.	4641.500	30.16 %	HIGH GROUND
2	19025.	4756.250	30.90 %	RHIZOPHERA
3	6028.	1507.000	9.79 %	AVICENNIA
4	4302.	1075.500	6.99 %	SALT FLATS
5	0.	0.000	0.00 %	SUPRA-TIDAL GRASS LANDS
6	9791.	2447.750	15.90 %	WATER
7	0.	0.000	0.00 %	SANDY AREAS
8	3849.	962.250	6.25 %	CLOUDS AND SHADOWS

TOTAL NON-ZERO POINTS = 61561.
TOTAL NON-ZERO HECTARES = 15390.25
Percentages are Based on NON-ZERO points

TABLE 6. LANDSAT CLASSIFICATION OF CHAME

Histogram listing for file PARITA3

This image has 201 ROWS , 255 COLUMNS

This is a GIS data file
The VARIABLE name is MANGROVE FOREST OF THE RIO GRANDE

DATA VALUE	NUMBER OF POINTS	NUMBER OF HECTARES	%	DESCRIPTION
0	4219.	1054.750	0.00 %	BORDER
1	9497.	2374.250	22.29 %	HIGH GROUND
2	11162.	2790.500	26.19 %	RHIZOPHERA
3	8853.	2213.250	20.77 %	AVICENNIA
4	2351.	587.750	5.52 %	SALT FLATS
5	0.	0.000	0.00 %	SUPRA-TIDAL GRASS LANDS
6	10740.	2685.000	25.20 %	WATER
7	11.	2.750	.03 %	SANDY AREAS

TOTAL NON-ZERO POINTS = 42614.
TOTAL NON-ZERO HECTARES = 10653.50
Percentages are Based on NON-ZERO points

TABLE 7. LANDSAT CLASSIFICATION OF AGUADULCE

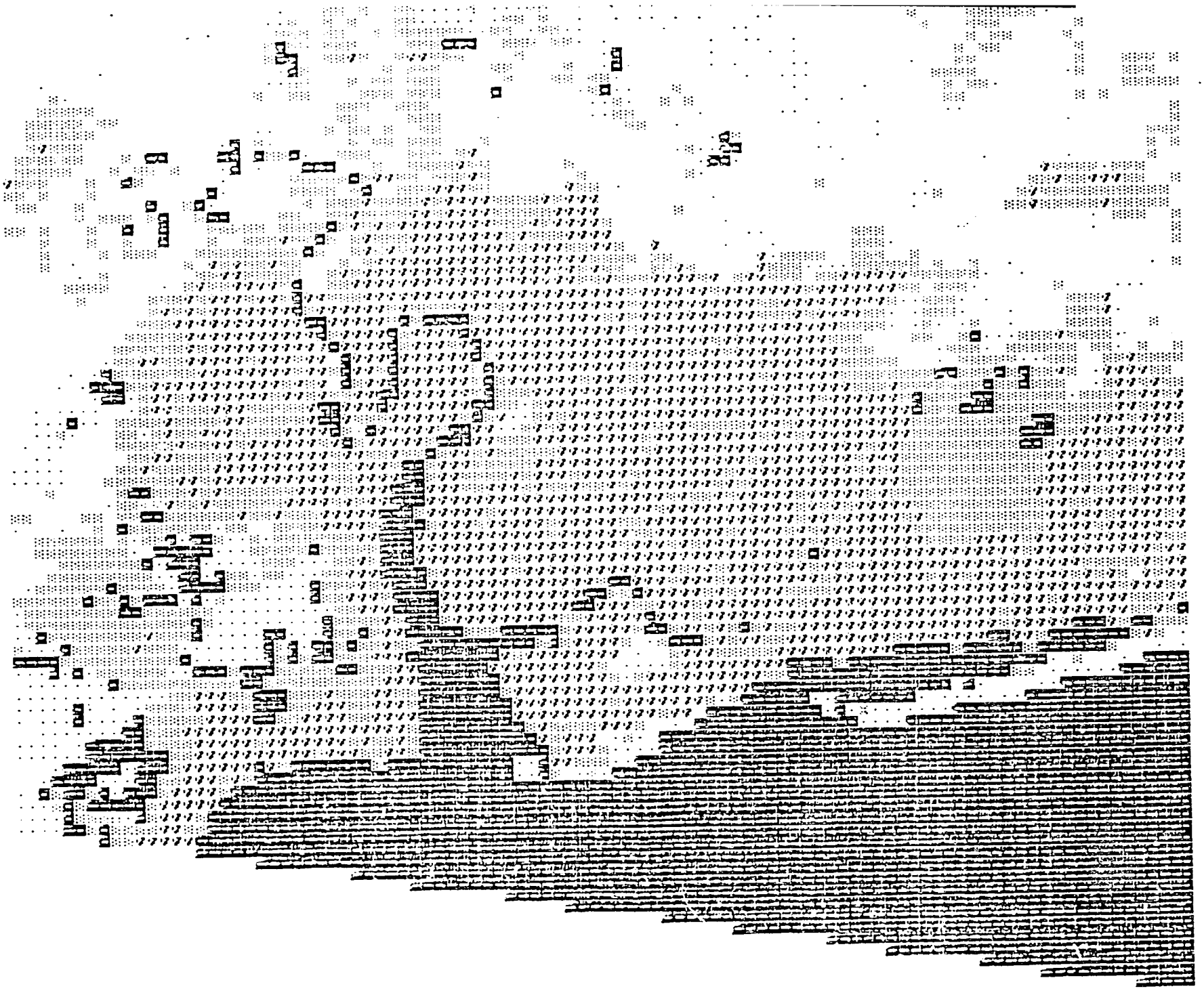

FIGURE 1. SYMBOL MAP OF AGUADULCE LANDSAT CLASSIFICATION

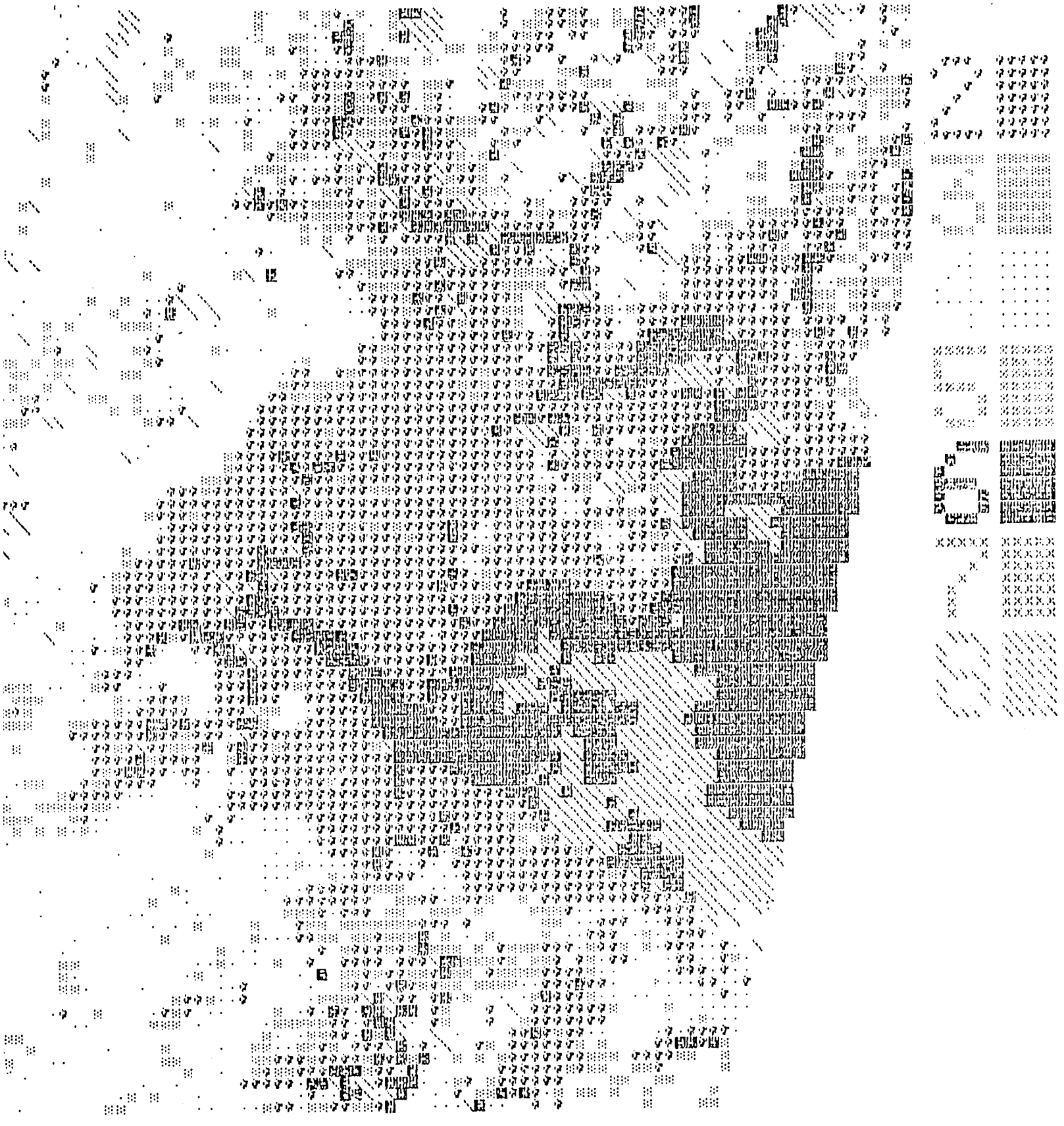

FIGURE 2. SYMBOL MAP OF CHAME LANDSAT CLASSIFICATION