Mangrove Mapping in Ecuador: the Impact of Shrimp Pond Construction

ARAM TERCHUNIAN
VICTOR KLEMAS
Center for Remote Sensing
College of Marine Studies
University of Delaware
Newark, Delaware 19716, USA

ALBERTO SEGOVIA*
AGUSTIN ALVAREZ
BRYON VASCONEZ
LUIS GUERRERO
Centro de Levantamientos Integrados de Recursos
Naturales por Sensores Remotos, CLIRSEN
Casilla 8216
Quito, Ecuador

ABSTRACT / A cooperative mangrove mapping project between the Ecuadorian Center for Remote Sensing (CLIRSEN) and the University of Delaware was begun in August 1982. The objectives of the project were to create historical maps of mangrove ecosystem extent and change, while transferring aerial photographic interpretation techniques to Ecuadorian personnel. The result of this cooperation was a series of three 1:25,000 scale maps of historical mangrove extent and change from 1966 to 1982 in the southern Gulf of Guayaquil. This multitemporal study showed a 16% decrease in mangrove extent and a 27% increase in shrimp pond development. If these rates of change prevail into the future, mangroves in Ecuador will reach parity with shrimp ponds in 1984 and completely disappear by mid-1990. Recognizing the significance of this loss to shellfish and fish production along the coast, Ecuadorian scientists at CLIRSEN have subsequently initiated a nationwide mangrove mapping program to create a historical base for future mangrove management strategies.

Mangrove forests are important coastal ecosystems providing both organic detritus and habitat for the juvenile marine organism (Lugo and Snedaker 1974, Heald and others 1974, Odum and others 1982), as well as biomass and primary productivity of fish and shellfish products that are important to the economies of many Caribbean and Central American countries (Lugo and Brinson 1979, Pannier 1979, D'Croz and Kwiecinski 1980). However, mangrove is being cut down in many Central American and Caribbean countries in order to provide firewood or building materials, and the swamps are being destroyed by new construction and the development of shrimp ponds. Shrimp ponds are artificially bermed holding ponds constructed to raise shrimp to a marketable size for human consumption. Intertidal areas are chosen to take advantage of natural tidal flushing. Similarly, heavy urban and industrial development of coastal zones is causing an influx of pollutants into coastal waters, further endangering coastal fisheries production. Multispectral remote sensing techniques have been successfully used to estimate macrophytic biomass in wetlands systems (Jensen 1980, Hardisky and others 1984) and to discriminate suspended organic from inorganic matter in coastal waters (Philpot and Ackleson 1981, Philpot 1981).

KEY WORDS: Mangroves; Shrimp ponds; Ecuadorian Center for Remote Sensing; Coastal ecosystems; Mapping

*Director, CLIRSEN.

Controversy about the biologic productivity, economic potential, and environmental necessity of mangroves has led to conflicts over their exploitation and conservation (UNESCO 1980). Since the majority of mangroves are located in developing countries with inadequate management structures (Bacon 1980), international cooperation between development and underdeveloped nations has begun to form a comprehensive managment scheme. The primary information sources for mangrove management are the aerial photographs and historical maps of mangrove areas. The advantages of remotely sensed data in mapping coastal salt marshes in temperate regions has prompted many developing nations to use remote sensing for mangrove inventories (Bartlett and Klemas 1980, Klemas 1981). The Ecuadorian Center for Remote Sensing, CLIRSEN (in Quito, Ecuador), in conjunction with the University of Delaware, Center for Remote Sensing (in Newark, New Jersey, USA), began an inventory program in August 1982. The object of this program was not only to inventory the past and present mangrove resources, but also to instruct Ecuadorian personnel in the various remote sensing techniques currently used in the United States and elsewhere. Four remote sensing platforms were considered for the program: Landsat, airborne MSS, radar, and aerial photographs.

Landsat images of suitable quality were unavailable due to excessive cloudiness, and undesirable due to the lack of adequate local digital analysis capability (manual interpretation was deemed too small-scale for user needs). Airborne MSS and radar were rejected because of the high cost and the unavailability of historical data. Thus, aerial photographs were chosen because of their desirable scale (1:10,000–1:60,000), historical availability, low cost, and ease of interpretation.

Procedure

A pilot area, representative of Ecuadorian mangroves in general, was chosen to determine the utility of using black-and-white aerial photographs to delineate mangrove environments and species. Although much information regarding salt marsh interpretation with remote sensing is readily available, the authors noted a distinct scarcity of mangrove interpretation information in the literature. Although interpretation techniques regarding mangroves do exist (Francis 1955), information was difficult to obtain.

A mangrove classification/identification system based on the pilot area was devised. Considerable work on the mangrove ecosystem in the Golfo de Guayaquil in Ecuador (see Figure 1a and b) has been performed by Horna (1980 and 1981) and Cintron and others (1981). The basic knowledge of the structure of the mangrove ecosystem in this particular area aided greatly in the aerial photointerpretation. The basic ecostructure of the Guayaquil mangroves is given in Figure 2. The mangrove forests consist of two principal zones. The zone bordering the rivers is usually sp. *Rhizophora* (red mangrove), behind which exists a zone of mixed mangroves, usually sp. *Avicennia* (black mangrove) and sp. *Laguncularia.* These different zones can easily be distinguished on aerial photographs, not only by different textures and tones that the different species exhibit, but also because of the difference in height between sp. *Rhizophora,* sp. *Avicennia,* and sp. *Laguncularia.* The difference in height— >15 m, 6–15 m, and <5 m, respectively—allowed species identification with photos of poor contrast or with areas of unexpected species location. Mangrove forests may also contain zones of salt deposits (salinas) and mud deposits (lodo or pantone). Since these are all areas of very high salinity, they were classified as salinas in various stages of development. On the photographs they were recognized either as white areas or varying shades of white. The difference in appearance was a function of the varying stages of development (that is, young to mature), and the season (rainy or dry), which changed the water content, and thus the consistency and appearance, of the salt or mud. The transition from mangrove to upland vegetation was quite easy to recognize because of the sharp tonal differences (mangroves being much darker than upland vegetation) and the fact that many mangroves were bordered on the upland side by salinas.

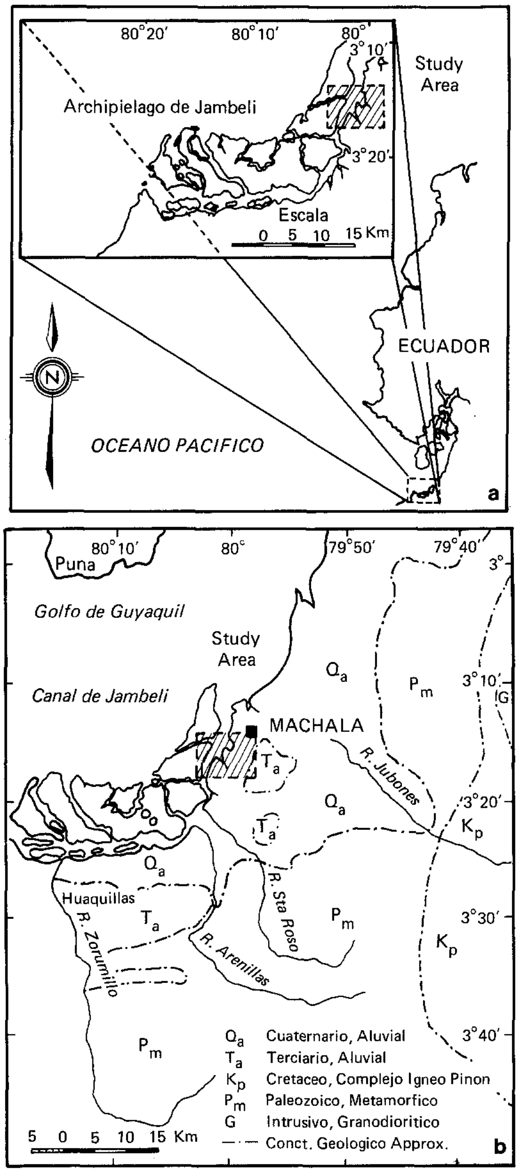

Figure 1. (a) Location map. (b) Regional geology. From Coronel and Ayon (1980).

Agricultural land was differentiated from mangroves by the rectangular shape of the cultivated fields. Any vegetation that was not identified as mangrove or agricultural was called upland. Sandbars, beaches, and natural water bodies were identified by their obvious characteristics. Intertidal flats were labeled as sandbars, and no differentiation was made between upland drainage water and estuarine waters.

Manmade urban features such as buildings, roads, and docks were identified on the basis of their appearance. Shrimp ponds (camaroneras), an important modifier of Ecuadorian wetlands, were identified as

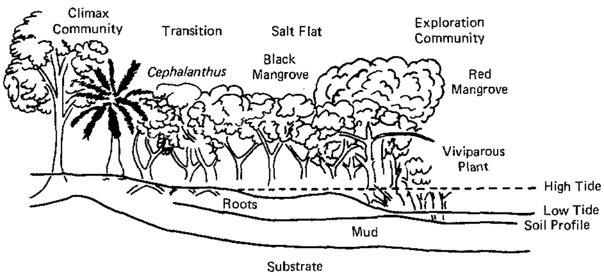

Figure 2. Typical mangrove succession. From Horna (1980).

rectangular or triangular holding ponds located near or in former mangrove areas. The biological impact of shrimp pond development in mangroves is only briefly touched on in this text, and the reader is referred to more detailed information in the literature (Unesco 1980). It should be noted, however, that shrimp pond development, land reclamation, and urbanization were primary motivators behind the Ecuadorian government's initiation of a comprehensive management program.

A pilot area was chosen in the southwestern Golfo de Guayaquil (see Figure 1a). The study area consisted of a mangrove-covered peninsula bounded to the east by the Golfo de Guayaquil and to the west by a large estuary (Estero Santa Rosa). West of this lay more mangroves on the mainland, and these blend into salinas and eventually upland vegetation. The area was selected for study because it represents many of the possible mangrove environments, including the gulf coast, estuaries, mangroves, urban areas, salinas, and camaroneras.

Historical black-and-white photographs at scales of 1:20,000 and 1:60,000 were gathered for 1966 and 1977, respectively. A mosaic was prepared for each year with at least 25% side lap and 55% end lap. The photographs were stereoscopically interpreted by Ecuadorian personnel who had received instruction in aerial photointerpretation from University of Delaware instructors. U of D instructors also inspected the interpreted photos to assure correct identification. The 1:60,000 scale photos were also interpreted using a stereo zoom transfer scope at an enlarged scale of 1:25,000, which greatly reduced errors and increased detail.

Mangrove boundaries were drawn with a 0.3-mm [6 m (1:20,000) and 7.5-m (1:25,000)] rapidograph pen. Photographs were accepted when the average error of 60 randomly selected boundaries, representing drainage and mangrove identification, were within 2 m (for both 1:20,000 and 1:25,000 scales) of the Delaware interpretation. Thus, the total errors were ±8 and ±9.5 m for the 1:20,000 and 1:25,000 scale photos, respectively.

These error values were considered acceptable for user needs of historical data. The interpretations were transferred to 1:25,000 using an Art-O-Graph map projector. The common 1:25,000 scale was chosen because it was compatible with existing topographic sheets. The photomosaics, however, were nonrectified images, so they did not exactly match the rectified maps. These maps were later expanded to a 1:10,000 scale for specific agencies' use.

The 1982 photos taken at a scale of 1:10,000 were interpreted in the same manner as the previous two sets of photographs, and the error of interpretation was ±5 m. In addition to the standard 1:25,000 map, a 1:10,000 scale map of the area was prepared for use by other Ecuadorian agencies.

Evaluation of land cover change of the area was computed by overlaying a 1-mm grid sheet and counting the number of squares of each cover type. Although this is not an elaborate technique, it was effective. This technique was then checked by planimeter and found to be within ±1.5%. The technique gave the Ecuadorians experience in two methods and increased understanding of the process. Field surveys to check the 1982 map were performed in June 1983, and the draft interpretations were subsequently finalized. The large scale (1:10,000) and excellent quality of the photographs yielded results that were easily verifiable and useful.

Results

The products of this pilot investigation are three maps of land cover/use change in the Machala–Pto. Bolivar areas. The first map, 1966, depicts the area in a near-natural state. Subsequent maps, 1977 and 1982, show the mangrove area lost to shrimp pond development, urbanization, and agricultural uses.

Two methods were used to project the changes in the mangrove ecosystem based on land-use changes determined for the period 1966–1982. The first method based on five-year increments uses the formula:

$$\frac{\begin{array}{c}\%\ \text{change in}\\ \text{land cover area}\\ \text{1982–1977}\end{array}}{5} = a\ (\text{change in land cover/year})$$

$$\frac{\begin{array}{c}\%\ \text{change in}\\ \text{land cover area}\\ \text{1977–1966}\end{array}}{11} = b\ (\text{change in land cover/year})$$

Table 1. Changes in land cover/use in the pilot area Machala–Pto. Bolivar, 1966–1982. [Cambios en el uso de la tierra en el area piloto Machala–Pto. Bolivar desde 1966 a 1982.]

	Urban [Urbana]		Mangrove [Manglares]		Shrimp ponds [Camaroneras]		Rivers [Rios]	
Year	ha	%	ha	%	ha	%	ha	%
1966	256.69	3	4692.88	54.84	0	0	1437.45	16.80
1977	434.66	5.08	4231.70	49.50	834.23	9.75	1514.46	17.70
1982	588.50	6.87	3294.08	38.50	2330.67	27.24	1465.65	17.13

Table 1. Continued.

Areas of salt deposits [Salinas]		Upland vegetation [Vegetacion tierra alta]		Agriculture [Zona agricola]		Totals [Totales]		Margin of error
ha	%	ha	%	ha	%	ha	%	
1087.72	12.71	466.32	5.45	615.19	7.19	8556.25	100	±1.80
478.52	5.59	332.15	3.88	730.23	8.54	8555.95	99.98	±0.53
162.56	1.19	139.37	1.63	634.73	7.42	8555.05	99.95	±0.22

$a - b = c$ (difference in annual rate of change between 1982–1977 and 1977–1966)

$5(a + c) = X_1$ = % increase in land cover 1982–1987

$5(2a + c) = X_2$ = % increase in land cover 1987–1992

This method attempts to account for the increase in the annual rate of land cover change in the two time periods measured. The second projection method employed was a time trend analysis (Hamburg 1974) which yields a best fit, linear approximation of change. The agreement between the two methods is good over the short term, but degrades rapidly for longer time periods, that is, greater than three years. Since insufficient annual data were available for this projection method, the results are not presented.

A brief summary of the data (Table 1) shows that shrimp pond development began between 1966 and 1977 (1975–1977 according to local sources). Between 1977 and 1982, construction tripled to its current level of 27.24%. Clearly, this is the dominant change in the mangrove habitat. During the 27.24% increase in shrimp ponds, there was a 16.34% decrease in mangroves, again mostly between 1977 and 1982 (9%). The graph (Figure 3) shows that regardless of the project method employed, parity between mangroves and shrimp ponds would be reached in 1983–84.

The salinas areas were the hardest hit by shrimp pond construction, decreasing from a high of 12.71% in 1966 to 1.63% in 1982. Most of the change (7.12%) took place from 1966 to 1977, and only 5.29% occurred from 1977 to 1982. This was because the salinas were the first areas to be used for shrimp ponds; the mangrove areas were used subsequently. The salinas areas were also used for urban areas, and of the 5.29% lost during the 1977–1982 period, about 2% was to urban uses. The salinas are expected to be extinct by early 1983. The urban areas (Puerto Bolivar and Machala) are experiencing a steady growth, from 3% to 5.08% to 6.87% for 1966, 1977, and 1982, respectively. This linear growth will probably continue in the foreseeable future. Agricultural land use appears to be stable, but a slight reduction was noticed from 1977 to 1982 (8.54%–7.42%). It is expected that agricultural land use will stabilize at around 7.5%. Upland vegetation, a matorral type growth, has steadily decreased because of agricultural pressures, and it is expected to disappear by mid-1983.

The results point out the rapid modifications taking place in the pilot area and stress the need for a comprehensive management plan. The results also show that black-and-white photos (scale 1:10,000–1:25,000) were sufficient for mangrove habitat identification and mapping.

Future Research Needs

The application of detailed remote sensing procedures such as the measurement of temporal changes

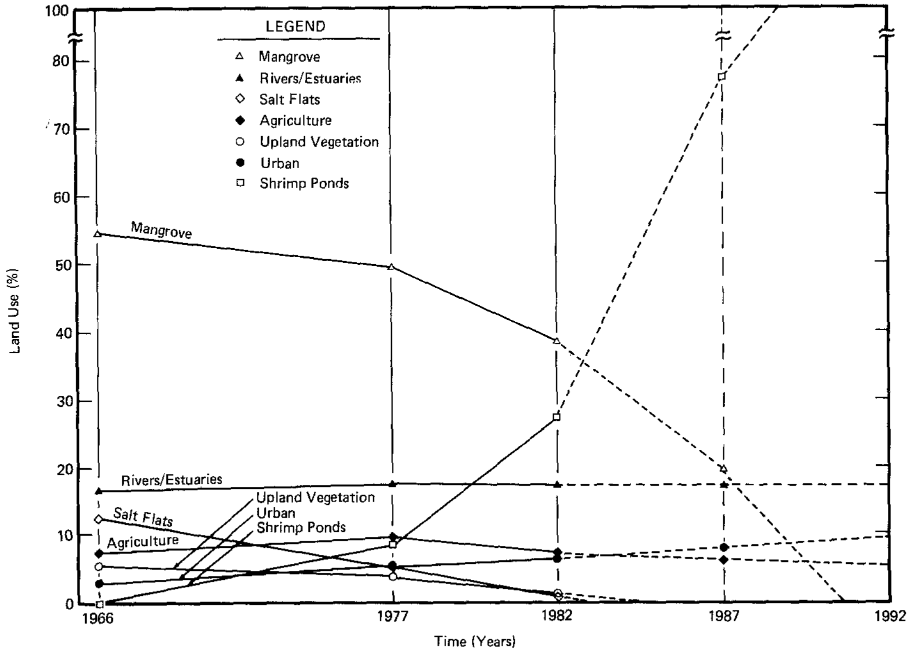

Figure 3. Changes in land use in the pilot area Machala–Pto. Bolivar in the years 1966–1977–1982 and projected changes for the years 1987 and 1992.

and biomass observation is a significant tool to be used in overall mangrove ecosystem management.

Thematic maps of temporal and spatial change yield valuable insight into the direction of change in the ecosystem. Biomass observations are also very useful in determining biological productivity in mangroves, shrimp ponds, and other portions of the ecosystem. The synthesis of this information provides an excellent tool for monitoring and directing change in the ecosystem.

A multilevel sensor system consisting of satellite, radar, and aerial photographs (color IR), supplemented by field observations, is the best system for mapping mangrove ecosystem changes. The satellite data (Landsat and TIROS-N/AVHRR) provides the broad picture, but lacks detail because of excessive clouds and poor resolution. The radar provides cloud-free images with excellent resolution, and the aerial photographs (preferably color IR) provide biomass observations and check the radar-derived information as well as give historical data.

Information provided by Landsat and radar exists; however, TIROS-N/AVHRR and color IR aerial photography does not and must be collected. Obtaining and interpreting the multilevel sensor data to produce thematic information will provide an excellent method of making thematic maps at a minimum of cost. These maps (scale 1:10,000–1:25,000) would be a valuable asset in overall mangrove ecosystem management.

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