Using Remote Sensing Techniques to Distinguish and Monitor Black Mangrove (*Avicennia germinans*)

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ABSTRACT ▄

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Black mangrove [*Avicennia germinans* (L.) L.] is found at several locations along the Texas gulf coast. A hard freeze in December 1983 severely damaged the populations, but the extent of damage has not been determined. Color-infrared (CIR) aerial photography was evaluated to determine the current distribution of black mangrove. Ground reflectance measurements were made on black mangrove and associated plant species and soil to help interpret CIR photographs. Ground surveys were conducted to verify aerial photos. Black mangrove had a distinct red to dark red CIR image response that made it easily distinguishable from other vegetation and soil. Ground reflectance measurements showed that black mangrove had lower visible red (0.63–0.69 μm) reflectance than associated plant species and soil, which contributed greatly to its image response. The low visible reflectance of black mangrove was attributed to its dark green leaves. Major concentrations near Port Isabel-South Bay and Port Aransas, on the lower and mid Texas coast, respectively, had largely recovered from the freeze and were actively growing, producing flowers and seed. Major populations near Port O'Connor on the upper Texas coast were killed by the 1983 freeze, but many young plants that had grown from seeds or that survived the freeze due to the protection provided by taller plants were producing flowers and seed. Computer-based image analyses of CIR film positive transparencies showed that black mangrove populations could be quantified accurately. This technique can permit 'percent area estimates' of black mangrove which can be useful to monitor changes in its distribution over time. These results showed that remote sensing techniques can be useful to distinguish black mangrove and determine its extent along the Texas gulf coast.

ADDITIONAL INDEX WORDS: *Color-infrared photography, reflectance, Texas gulf coast.*

INTRODUCTION

Mangrove communities are characteristic of the tropics and subtropics, but one or two more tolerant species have penetrated into the warm temperate zones of both hemispheres (CHAPMAN, 1975). Although four mangrove species occur in the northern Gulf of Mexico region, only the black mangrove [*Avicennia germinans* (L.) L.] extends into Texas (SHERROD and McMILLAN, 1981). Viable red mangrove (*Rhizophora mangle* L.) seedlings wash ashore on Texas beaches (CORRELL and JOHNSTON, 1970; McMILLAN, 1971; GUNN and DENNIS, 1973), but no naturally occurring plants have been observed. Furthermore, SHERROD *et al.* (1986) reported the destruction,due to subfreezing temperatures, of transplants of red man-

grove at the mouth of the Rio Grande and at South Padre Island in Cameron County, Texas.

SHERROD and MCMILLAN (1981) reported on the distribution of black mangrove along the Texas coast. They used herbarium records, aerial photographs, and field reconnaissance to elucidate the species' past and present distribution. Sherrod and McMillan suggested that three major mangrove concentrations, *i.e.*, Cavallo Pass in Calhoun County, Harbor Island in Nueces County, and the Port Isabel-South Bay area of Cameron County, represented areas of continuous mangrove occurrence throughout the 20th century. During favorable periods, distribution expanded from these three centers and during unfavorable periods the populations contracted (SHERROD and McMILLAN, 1981). They concluded that black mangrove had increased in abundance between the 1930's and late 1970's.

On 24 December 1983, a cold front moved

through Texas dropping air temperatures throughout the coastal area to well below freezing. At Brownsville, near the southern tip of Texas, a low of −6.11 C was recorded and there were 54 consecutive hours below 0°C (SHERROD *et al.*, 1986). More northern coastal areas experienced lower extreme temperatures and longer durations of below freezing temperatures.

LONARD and JUDD (1985) reported the effects of this freeze on the native woody plants in the lower Rio Grande Valley of Texas. Black mangrove was one of eight species seriously damaged. SHERROD *et al.* (1986) reported that the freeze resulted in the total destruction of experimental plantings of red mangrove near the mouth of the Rio Grande and on South Padre Island in Cameron County, Texas. Further, 50 large red mangrove of unknown (but suspected planting) origin on South Padre Island were also killed. Subsequent censuses by the authors showed that about 40 percent of the black mangroves in the immediate vicinity of the red mangroves had resprouted from the basal 0.3 m in August 1984. In June 1985, all of the red mangroves were dead, but most of the black mangroves that had resprouted were flowering. SHERROD and McMILLAN (1985) provided a photograph of the recovering populations on South Padre Island. Recovery was from germinating seedlings and small (less than 0.3 m tall) plants or resprouting from the base of taller multiple-stemmed plants.

We used color-infrared (CIR) aerial photography (and ground truthing) to document the distribution and abundance of black mangrove along the Texas coast. The purposes of this investigation were to: (1) establish characteristics of the spectral reflectance for black mangrove to facilitate its detection using CIR photography. (2) compare the present distribution and abundance (subsequent to the 1983 freeze) with that reported by SHERROD and McMILLAN (1981) prior to the 1983 freeze. (3) provide a baseline using a single repeatable and quantifiable technique for the entire Texas coast so that the spread or contraction of mangrove over time can be documented. The baseline and subsequent censuses also can provide a means of assessing the effects of human perturbations to mangrove communities. Aerial CIR photography has been used to document the distribution of mangrove in several areas

(*e.g.* REARK, 1975; ROSS, 1975; SAENGER and HOPKINS, 1975; SHERROD and McMILLAN, 1981), but the characteristics of its spectral reflectance have not been established and a technique has not been developed to quantify its populations.

MATERIALS AND METHODS

This study was conducted along the gulf coast of Texas from Boca Chica at the mouth of the Rio Grande River to Galveston Island on the upper coast. Plant canopy and soil reflectance measurements, aerial photographs, and ground truth observations were conducted for this study. Reflectance measurements were made to help interpret aerial photographs, while ground truth observations were conducted to verify aerial photos. Aerial photographs and reflectance measurements were obtained at different dates in the growing season to study black mangrove and associated vegetation in various phenological stages.

Reflectance measurements were made in the field near Port Isabel, Texas, in June, August, September, and December 1987. Plant canopy reflectance measurements were made on black mangrove, shoregrass (*Monanthochloe littoralis* Engelm.), vidrillos (*Batis maritima* L.), screwbean (*Prosopis reptans* Benth.) and mixed herbaceous species (sedges, grasses, and broadleaved herbs). Shoregrass, vidrillos, screwbean, and mixed herbaceous species are typical plant species that grow in association with black mangrove. Reflectance measurements were also made on both wet and dry soil. Measurements (nadir) were made on ten randomly selected plant canopies (each species) and soil surfaces on each date using a hand-held NASA GSFC MARK-II radiometer (TUCKER *et al.*, 1980). Both red (0.63–0.69 μm) and near-infrared (0.76–0.90 μm) measurements were obtained using a sensor with 15° field-of-view placed 1.8 m above ground. Reflectance measurements were made between 1100 and 1500 hours under sunny conditions. Field radiometric measurements were corrected to reflectance using a reflectance standard at a solar irradiance reference condition common to both (RICHARDSON, 1981).

Kodak[1] Aerochrome color-infrared (CIR)

Trade names are included for the benefit of the reader and do not imply endorsement of or a preference for the product listed by the U.S. Department of Agriculture.

(0.50–0.90 μm) type 2443 film was used for all aerial photos. CIR film has sensitivity in both the visible (0.50–0.75 μm) and near-infrared (0.75–0.90 μm) spectral regions. Photographs were taken with either a Hasselblad or Fairchild camera. The Hasselblad camera (150-mm lens, 5.7- by 5.7-cm format) was equipped with a minus blue/yellow filter. The aperture setting was f8 at 1/500 s. Photographs were taken at scattered locations along the lower gulf coast (Port Mansfield to Boca Chica) on June 2, August 8, and October 13, 1987. The Fairchild camera (305-mm lens, 23-by 23-cm format) was equipped with Kodak Wratten 15 and Kodak Wratten color correction 50 blue filters. The aperture setting was f9.6 at 1/100 s. Photographs were taken at scales of 1:1,500, 1:2,000, 1:3,000, and 1:5,000. The Fairchild camera was used to obtain photographs near Port Isabel on April 15 and November 23, 1987. Additional photographs were taken on November 3, 1987, near Galveston, Port O'Connor (Cavallo Pass), and Port Aransas (Harbor Island), Texas, of areas where black mangrove was known to occur (SHERROD and McMILLAN, 1981). Sporadic locations along the mid to lower gulf coast (Corpus Christi to Port Mansfield) were photographed on November 4, 1987. Photographs were also obtained near Port O'Connor on September 27, 1988. All photographs (nadir) were obtained between 1000 and 1500 hours under sunny conditions using either a Cessna 182 or 206 aircraft.

After viewing CIR transparencies, ground surveys were made at many of the sites to verify the presence of black mangrove. Some sites were inaccessible by land; consequently, low altitude (100 m) aerial or boat reconnaissance was made of these areas to verify the presence of black mangrove.

The CIR photographic transparency of black mangrove near South Padre Island was digitized using an I²S Model 70 image processor with a video camera input accessory consisting of a Cohu Model 2800-B camera and light table. The I²S system was interfaced to an Hewlett Packard 1000 computer. Red (0.62–0.70 μm), green (0.51–0.58 μm), and blue (0.42–0.50 μm) filters were used to separate the near-infrared, red, and green sensitive film layers of the CIR transparencies. The image processor's Select function was used to merge the three film layers into a CIR composite. The global thresholding

technique (CASTLEMAN, 1979) was used on a ratio image of the CIR transparency. The Divide function of the image processor was used to obtain a ratio image by dividing the green sensitive film layer by the visible red sensitive layer. A comparison computer program was used to identify black mangrove in the ratio image and replaced the same areas on the original digitized CIR composite image with color pixels.

A photointerpretive procedure was used on the same transparency digitized on the I²S image processor to compare differences in classifications. A "mask" was made of the transparency by tracing areas where black mangrove was thought to occur onto a transparent paper overlay of the transparency. Areas where black mangrove were thought to occur were coded black and the remainder of the mask was left white. The "masked" tracing was digitized with an image processing system that consisted of a PC-AT clone computer having a Matrox MVP/AT board and IMAGE-PRO II processing software. The digitized "masked" tracing was subjected to the "index replacement" function which permitted the selection of pixels that represented areas coded as black mangrove in the mask. This technique permitted the computer to produce a binary image that delineated areas of black mangrove as black colored pixels and the remaining areas as white colored pixels. The IMAGE-PRO II "analysis" functions were used to determine the percentage of black mangrove in the "mask."

Visible and near-infrared reflectance data were analyzed using analysis of variance techniques. Duncan's multiple range test was used to test statistical significance at the 0.05 probability level among means (STEEL and TORRIE, 1980).

RESULTS AND DISCUSSION

Mean light reflectance measurements for black mangrove, three associated plant species and mixtures of plant species, and soils at the visible and near-infrared wavelengths for four dates in 1987 are given in Table 1. In June, dry bare soil had significantly higher (p = 0.05) visible reflectance than the wet soil and four plant species and mixtures of species; whereas black mangrove had lower visible reflectance than the other plant species, mixtures of species, and

Table 1   *Mean light reflectance measurements of four plant species, mixed herbaceous species, and soils on four dates for the visible and near-infrared (NIR) wavelength intervals. Reflectance measurements were made near South Padre Island, Texas.*

Plants and Soils	Date and reflectance values[1]							
	June		August		September		December	
	Visible	NIR	Visible	NIR	Visible	NIR	Visible	NIR
Black mangrove	4.0 f	30.8 c	4.0 d	31.8 a	2.9 e	31.9 a	2.5 e	37.2 a
Mixed herbaceous species	8.4 c	33.5 b	9.5 b	24.6 b	8.2 c	21.1 b	4.2 d	23.4 c
Screwbean	7.1 d	41.3 a	7.3 c	30.4 a	7.3 cd	29.5 a	6.9 b	29.4 b
Shoregrass	5.8 de	21.2 e	9.8 b	18.3 c	7.5 cd	15.2 c	3.8 d	16.9 d
Vidrillos	5.7 e	23.9 d	8.1 c	24.6 b	6.7 d	23.1 b	5.0 c	19.7 d
Dry bare soil	31.5 a	33.8 b	24.7 a	31.2 a	24.4 a	31.2 a	—[2]	——
Wet bare soil	12.6 b	15.5 f	10.2 b	13.8 d	10.6 b	14.6 c	11.0 a	17.7 d

[1]Values within a column at each date of sampling followed by the same letter do not differ significantly at the 0.05% probability level according to Duncan's multiple range test.

[2]The area had received rain prior to measurements and consequently there was no dry bare soil.

soils. The high visible reflectance of the dry bare soil was attributed to its whitish gray color. Conversely, the lower visible reflectance of black mangrove was primarily attributed to its darker green foliage which absorbed more of the visible light than did the lighter colored foliage of the other plant species and mixtures of species, and lighter tones of the soils. Black mangrove had mostly mature dark green leaves in June, but its upper canopy had a number of young light green leaves. In addition, it was flowering. Despite the presence of some lighter foliage and white flowers, black mangrove had an overall darker green color than the other species. Black mangrove also had darker in-canopy shadowing than the other plant species and mixtures which probably contributed to its lower visible reflectance (RICHARDSON *et al.*, 1975). At the near-infrared wavelength, screwbean had the highest reflectance and shoregrass had the lowest. Near-infrared reflectance in vegetation is highly correlated with plant density (MYERS and ALLEN, 1968; EVERITT *et al.*, 1986). An overhead view of the plant species and mixtures of species showed that screwbean had greater leaf density and less gaps (sun flecks) in its canopy than did the other species and mixtures, whereas shoregrass had the least density and most gaps. The high near-infrared reflectance of the dry soil and lower near-infrared reflectance of the wet soil agrees with the findings of other researchers (BOWERS and HANKS, 1965; SKIDMORE *et al.*, 1975).

Visible and near-infrared reflectance values for the four plant species, mixtures of species, and soils in August and September followed a similar pattern to those shown in June. Despite the presence of some young light green leaves in its canopy in August, black mangrove had a much darker green color than the other vegetation giving it significantly lower (p = .05) visible reflectance. By September, black mangrove had very few lighter colored leaves and its visible reflectance was lower than in August, and continued to be significantly lower (p = 0.05) than the other vegetation and soil. The near-infrared reflectance of black mangrove did not differ from that of screwbean and dry bare soil in either August or September.

Visible reflectance values for all the plant species and mixtures of species were lower in December than on the previous dates (Table 1). This can be partially attributed to the wet soil background underneath the plants; the area had received rain two days prior to making measurements. However, the foliage colors on the plant species and mixtures of species had also changed by December. Despite the overall lower visible reflectance values, black mangrove had a uniform dark green foliage color in December giving it significantly lower (p = 0.05) visible reflectance than the other vegetation and wet soil. At the near-infrared wavelength, black mangrove had significantly higher (p = 0.05) reflectance than the other vegetation and soil. An overhead view of black mangrove showed that its canopy had greater leaf density and less gaps than on the other dates, which probably contributed greatly to its higher near-infrared reflectance.

Figure 1 (lower) shows a CIR positive print of a large population of black mangrove near South Padre Island, Texas. The print is a 3X enlargement of a 70-mm aerial photo (original
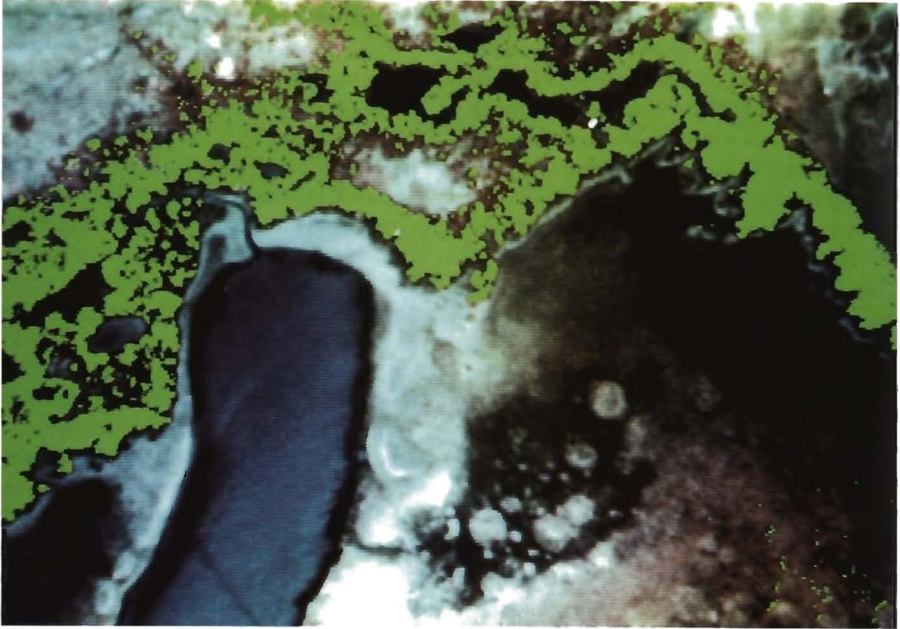
scale 1:5,000) taken on June 2, 1987. Black mangrove has a distinct red image response compared with the lighter shades of magenta to pink of vidrillos and mixed herbaceous species. Dry bare soil areas have a whitish-gray image tone, wet bare soil has a brown tone, mud has a black tone, and water (shallow) is blue. The red image of black mangrove was primarily attributed to its low visible reflectance, but its generally high near-infrared reflectance also contributed to its image response (Table 1). Additional black mangrove populations could be easily distinguished on other CIR photos taken along the lower Texas coast. Ground truth reconnaissance for eight randomly scattered sites selected near Boca Chica, South Bay, Laguna Vista, and Port Isabel from CIR positive transparencies gave 100% correct recognition of black mangrove. Ground truth also showed that these plants had fully recovered from the 1983 freeze and were actively growing producing flowers and seed. Black mangrove could be distinguished on 1:2,000, 1:3,000, and 1:5,000 scale photos. CIR photos taken in April, June, August, October, and November showed that black mangrove could be distinguished on all dates, but that its image tonal response varied from orange-red to red in April, June, and August, to dark red in October and November. The lighter to darker red CIR image response of black mangrove across the growing season was attributed to changes in its visible reflectance from summer to fall (Table 1). An analysis of CIR photos taken in the Port Mansfield area and of various spoil islands between Corpus Christi and Port Mansfield indicated that no black mangrove occurred in these areas. Apparently, black mangrove populations along the lower Texas coast are restricted to the area between Laguna Vista and Boca Chica with the largest concentrations located near Port Isabel, San Martin Lake and South Bay. The present distribution is similar to that mapped by SHERROD and McMILLAN (1981) before the 1983 freeze.

Black mangrove could also be easily detected in CIR photos taken in the Harbor Island area. Low altitude aerial reconnaissance confirmed that the major mangrove populations in the Harbor Island area as mapped by SHERROD and McMILLAN (1981) had survived the 1983 freeze and were actively growing. Ground visits

to the area in July 1988 revealed that these plants were flowering and producing fruit.

CIR photos taken of barrier islands in the Cavallo Pass area near Port O'Connor (upper Texas coast) where a major concentration of black mangrove was reported to occur (SHERROD and McMILLAN, 1981) indicated that the populations had been severely reduced in size. Ground visits to the area showed that the original black mangrove population was killed by the 1983 freeze and there was no regrowth from the base of the dead plants, as was common along the mid and lower coast. However, many young plants ranging from 24 to 90 cm in height, had either grown from seeds that survived the 1983 freeze or from small plants (< 30 cm tall) protected by the dense, taller plants (Sherrod and McMillan, personal communication). These were flowering and producing seed. Most of the young plants were on the perimeters of the islands. The remains of the original populations (i.e. dead plants) were evident in the interior of the islands, but few young plants occurred here. Based on aerial photos and ground observations, the mangrove population in the Cavallo Pass area was estimated to be < 5% of what it had been prior to the 1983 freeze (SHERROD and McMILLAN, 1981). Black mangrove could not be detected in additional CIR photos of sites near Galveston Island (upper Texas coast) where it had been previously reported to occur (SHERROD and McMILLAN, 1981), but ground visits to the area in July 1988 confirmed the presence of a few isolated plants less than 70 cm in height that were flowering.

Figure 1 (upper) shows the computer classification of the digitized CIR transparency of black mangrove near South Padre Island (Figure 1-lower). Areas classified as black mangrove in the upper print have a green code. A comparison of the computer classification to the CIR photograph indicated that areas where black mangrove occur have generally been delineated by the computer. The computer estimated that 17.5% of Figure 1 (lower) was comprised of black mangrove. In contrast, the computer estimated that 17.0% of the photointerpreters overlay map of Figure 1 (lower) was made up of black mangrove. The accuracy of the computer classification image analysis results are in close agreement to those reported for distinguishing weeds from agro-

nomic crops (MENGES *et al.*, 1985) and associated rangeland vegetation (EVERITT *et al.*, 1987). These results showed that computer analysis of CIR photographs can permit the quantification of black mangrove populations. This technique can permit 'percent area estimates' of black mangrove which can be useful to monitor its spread or contraction over time.

CONCLUSIONS

Ground reflectance measurements showed that black mangrove had lower visible red reflectance than associated plant species and soil on four dates (June, August, September, and December). The lower visible reflectance of black mangrove was primarily attributed to its darker green foliage which absorbed more of the visible light than did the lighter colored foliage of other plant species and the lighter tones of the soils. The low visible reflectance of black mangrove gave it a distinct red to dark red CIR image response that made it easily distinguishable from other vegetation and soil on six dates (April, June, August, September, October, and November).

We showed that the current distribution of black mangrove is restricted to only two major concentrations on the Texas coast: Harbor Island near Port Aransas and Port Isabel-South Bay area. Populations in these areas had recovered from the December 1983 freeze and were actively growing. A third major concentration at Cavallo Pass (SHERROD and McMILLAN, 1981), however, was severely reduced in abundance by the 1983 freeze. Dead mangrove plants had been replaced by young plants that had grown from seeds that survived the freeze or from plants < 30 cm tall that were protected by the dense, taller vegetation. These plants were flowering and producing seeds in July 1988.

These results demonstrated that CIR aerial photography is a useful tool for detecting black mangrove and demonstrating its distribution along the Texas coast. CIR photography combined with computer-based image analyses pro-

vides 'percent area estimates' of black mangrove abundance. The CIR film provides a record that can be stored and examined for comparative purposes at any point in time.

ACKNOWLEDGMENT

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Figure 1 *(Facing page)*. Color-infrared (CIR) positive print (lower) of a large population of black mangrove near South Padre Island, Texas. Black mangrove has a red image response. The print is a 3X enlargement of an original 70-mm photograph taken at an original scale of 1:5,000. The upper print is a computer-classified digitized image of the CIR film transparency (lower). Areas classified as black mangrove have a green code.

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□ ZUSAMMENFASSUNG □

Die Schwarze Mangrove [*Avicennia germinans* (L.) L.] tritt an verschiedenen Stellen der texanischen Küste auf. Ein starker Frost im Dezember 1983 hat die Vorkommen ernsthaft geschädigt, das Ausmaß der Schäden konnte aber noch nicht ermittelt werden. Color-Infrarot (CIR)-Luftaufnahmen wurden daher ausgewertet, um die gegenwärtige Verbreitung der Schwarzen Mangrove zu bestimmen. Um die CIR-Fotos zu interpretieren, wurden zunächst Messungen des Reflektionsvorkommens der Schwarzen Mangrove und der Begleitflora sowie des Bodens unternommen und Feldbeobachtungen zur Kontrolle der Aufnahmen durchgeführt.

Die Schwarze Mangrove hat eine spezifisch rote bis dunkelrote Farbe auf den Infrarot-Fotos, so daß sie leicht von anderer Vegetation und dem Boden unterschieden werden kann. Messungen der Oberflächenreflektion haben gezeigt, daß die Schwarze Mangrove im schwächer sichtbaren Rot (0.63–0.69 μm) reflektiert als andere Pflanzen und Böden, die erheblich zur Gesamtreflektion beitragen, wobei die geringe sichtbare Reflektion der Schwarzen Mangroven auf die dunkelgrünen Blätter zurückgeht.

Größere Vorkommen bei Port Isabel-South Bay und Port Aransas an der mittleren und südlichen texanischen Küste haben sich weitgehend von der Frostbeschädigung erholt und wachsen aktiv unter Ausbildung von Blüten und Samen. Größere Vorkommen bei Port O'Connor an der nördlichen texanischen Küste starben bei den 1983-Frösten ab, aber viele junge Pflanzen, welche aus Samen stammen, die den Frost überlebten, weil sie unter dem Blätterdach älterer Pflanzen geschützt waren, haben ebenfalls Blüten und Samen produziert.

Computergesteuerte Bildanalysen der CIR-Aufnahmen haben ergeben, daß die Vorkommen quantitativ genau ausgewiesen werden können. Diese Technik ist daher geeignet, die prozentuale Bedeckung mit Mangroven für spätere Vergleiche über längere Zeiträume aufzunehmen. Die Ergebnisse zeigen damit, daß Fernerkundungsmethoden sehr gut zur Unterscheidung der Schwarzen Mangrove und ihrer Verbreitung an der Küste von Texas angewendet werden können.—*Dieter Kelletat, Essen/FRG.*

□ RÉSUMÉ □

Les populations de mangrove noire (*Avicennia germinans* (L.) L.) de la côte du Texas ont été sérieusement endommagées par le froid intense de décembre 1983. La distribution habituelle des mangroves noires a été évaluée à partie de photos aériennes infrarouge couleur (IRC). Des mesure de réflectance in situ sur la mangrove et les espèces associées devaient permettre l'interprétation des photos IRC, et être accompagnées de missions de vérification de terrain. La mangrove noire a une réponse IRC rouge à rouge sombre qui la distingue bien des autres types de végétation et du sol. Les mesures de réflectance in situ montrent que la mangrove noire a une réflectance dans le rouge visible (0.63–0.69 μm) plus faible que les autres espèces et le sol, ce qui est attribué à la couleur vert foncé de ses feuilles. Les principales concentrations de popoulations près de Port Isabel-South Bay (côte Sud) et Port Arkansas (côte centrale) se sont bien rétablies de la gelée: leur croissance est active, elles produisent fleurs et graines. Les populations adultes de Port O'Connor (côte Nord) ont été détruites, mais de nombreuses jeunes plantes, issues de graines ou ayant survécu à l'abri des plantes plus hautes produisent fleurs et graines.—*Catherine Bressolier (EPHE, Montrouge, France).*

□ RESUMEN □

Se ha encontrado mangles negros (Avicenia germinans (L.) L.) en varios puntos de la costa del Golfo de Texas. Una fuerte helada en Diciembre de 1983 dañó fuertemente las poblaciones, pero la extensión del daño no ha sido determinada. Se ha estudiado fotografias infrarrojas (CIR) aéreas para determinar la distribución actual del mangle negro. Se realizó medidas de reflectancia de tierra sobre el mangle negro y plantas de especies asociadas y suelo para ayudar a la interpretación de las fotografias CIR.

Para verificar las fotos aéreas, se hizo también medidas en tierra. El mangle negro tiene una respuesta clara, rojo-rojo oscura, en la imagen CIR que le hace fácilmente identificable entre otras vegetaciones y el suelo. Las medidas de reflectancia del suelo muestran que el mangle negro tiene una reflectancia al rojo visible (0.63-0.69 um), inferior que las especies vegetales asociadas y el suelo, lo cual contribuye de una manera importante a su respuesta de imagen. La baja reflectancia visible del mangle negro se atribuye a sus hojas verde oscuro. Las mayores concentraciones, cercanas a la Bahia de Port Isable-South y a Port Aransas, en la costa baja y media de Texas, respectivamente, se han recobrado ampliamente de la helada y están creciendo activamente, produciendo flores y semillas. La mayor parte de las poblaciones cercanas a Port O'Connor en la parte superior de las costa de Texas murieron debido a la helada de 1983, pero muchas plantas jóvenes, que han crecido de las semillas o sobrevinieron a la helada debido a la protección de las plantas mayores, estaban produciendo flores y semillas. Los análisis de imagen por ordenador de las peliculas positivas CIR mostraron que las poblaciones de mangle negro podian ser cuantificadas con precisión. Esta técnica puede permitir "estimaciones de procentaje de área" del mangle negro que pueden ser útiles para detectar cambios en su distribución en el tiempo. Estos resultados han demostrado que las técnicas de muestreo remoto pueden ser útiles para distinguir el mangle negro determinar su extensión a lo largo de la costa del Golfo de Texas.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*