DISTRIBUTION OF MARINE GRASSES IN SOUTHERN LAGUNA MADRE

by

John L. Chin

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1977

The study area of this report encompasses approximately 80 square miles of lagoon bottom off the Arroyo Colorado River in Southern Laguna Madre, Texas. Climate is semi-aird as evaporation exceeds precipitation each year. Average monthly rainfall shows a bimodal distribution. Fresh-water runoff from the mainland into the lagoon is essentially negligible. Prevailing wind is from the southeast. Majority of geologic and hydrologic work is done by southeast and south-southeast winds. The daily effect of the tide decreases away from Brazos Santiago Pass. Furthermore, wind tides are the primary force controlling water circulation and inundation of lowlands in the Lower Laguna Madre.

Fieldwork was conducted from March through April 1977. Three hundred and eight bay-bottom samples were taken on a one-half mile grid. Field identifications and observations served as the basis for 1977 maps of seagrass distribution and density. Available mapping, from the Texas Parks and Wildlife Department, documented seagrass distribution and density for the years 1961, 1965, 1966, and 1969 to 1973.

Five marine spermatophytes occur on the Texas Gulf Coast: *Halodule wrightii*, *Ruppia maritima*, *Syringodium filiforme*, *Halophila engelmannii*, and *Thalassia testudinum*. All but *Thalassia* were encountered in the

study area in 1977 field studies. Leaf-tip morphology and leaf-blade configuration were used as the primary means of identification.

Comparative mapping of 1961 and 1977 data and changes observed by the Parks and Wildlife Department in 1965 and 1966 revealed marked changes in species distribution and density in the Lower Laguna Madre. *Halodule* total bottom cover has decreased as has its distribution and density from 1961 to 1977. *Syringodium* has not only encroached upon formerly pure *Halodule* stands, but in places it has totally replaced it as the dominant vegetative type. *Ruppia* has decreased in its distribution, occurrence, and density. No conclusions can be made regarding *Halophila* being that Parks and Wildlife did not, at any time, map its occurrence.

Major factors promoting and facilitating the northward expansion of seagrasses through Lower Laguna Madre since 1961 are: (1) stabilization of salinity through increased water circulation in Lower Laguna Madre (due to man-made changes), (2) subsidence of the ancient deposits underlying the lagoon bottom in the study area, (3) increased lagoonal bottom and water depth due to subsidence of the underlying deposits, (4) relative stability of the other physical factors controlling distribution and density of seagrasses.

INTRODUCTION

The Bureau of Economic Geology initiated a Wind Tidal Flat study of southern Laguna Madre in March 1977 for the purpose of determining the origin of wind-tidal flats and three associated islands (Los Bancos de en Medio); a part of that study was the determination of seagrass dis-

Objective of the seagrass study was to compliment mapping of sediment distribution, bathymetry, total organic carbon, trace element geochemistry, and infauna obtained from field studies. This report was designed to compliment the derivative maps of seagrass species distribution and density as well as fulfill the requirements for MNS 382--"Biology of Seagrasses."

STUDY AREA

The study area is that part of Southern Laguna Madre bounded by South Padre Island on the east and the mainland of Cameron and Willacy Counties on the west (fig. 1). The entire length of the lagoon is bisected by the Intracoastal Waterway (ICWW). The Arroyo Colorado Cutoff Channel occurs approximately half way through the length of the study area. Bay bottom included in the study area encompasses about 80 square miles (207.37 km^2). The northern limit coincides with Mullet Island and the southern limit coincides with Gabrielson Island. There is no sharp demarcation between land and water for much of the "lowlands" in the study area due to the changing water levels and wind-tide inundation. The eastern margin consists of wind-tidal flats on the lee side of South Padre Island. The flats are intermittently inundated by wind tides. The western margin consists of mainland shoreline deeply indented in places and characterized by a large number of mud flats surrounding natural "islands" (remnant clay dunes of a Holocene Rio Grande subdelta).

The study area lies in a climate classified as semi-arid (Thornthwaite, 1948). Average annual temperature is about 74^{o}F near

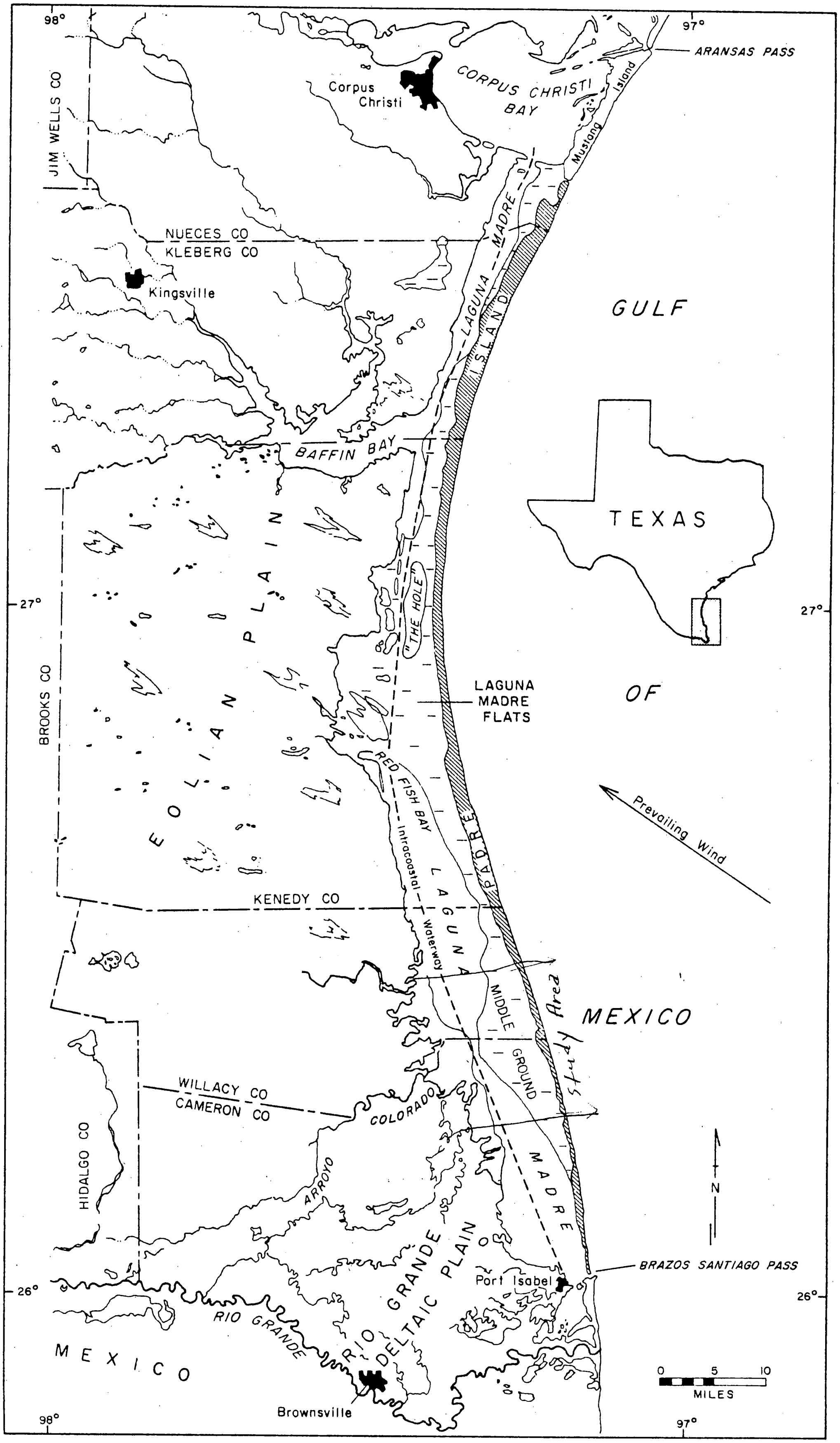


Figure 1. Padre Island-Laguna Madre area showing distribution of Laguna Madre Flats, Middle Ground opposite Arroyo Colorado, aeolian plain, and Rio Grande deltaic plain (after Fisk, 1959). Two natural passes that provide water exchange between Gulf of Mexico, bays and lagoons. Of particular interest is extreme width of wind-tidal flat opposite Arroyo Colorado.

Brazos Santiago Pass. Evaporation exceeds precipitation by approximately 24 inches per year. Rainfall data from the period 1953-1959 come from the Raymondville weather station and are taken from Breuer (1962) (table 1). Average monthly rainfall for the period 1953-1959 shows a bimodal distribution (McGowen, 1977). One maxima occurs in May while the other is in September (fig. 2). The first is associated with spring and summer thunderstorm activity and the second coincides with the summer hurricane season.

Fresh-water runoff from the mainland to the study area occurs via three floodways. The Rio Grande River has contributed very little water and sediment to the Gulf of Mexico since the completion of Falcon Dam in 1953 (McGowen and others, 1977) and can be considered negligible as a source of fresh-water runoff to the study area. Cayo Atascosa carries drainage and irrigation water but most of its water is impounded in the Laguna Atascosa Wildlife Refuge; it is dammed about 2.5 miles above its junction with the Arroyo Colorado Cutoff Channel (Brown and others, in preparation). North Floodway connects with the Rio Grande near Mission, Texas (as does the Arroyo Colorado) and can carry floodwaters from the Rio Grande when the river reaches flood stage as well as drainage from much of the Rio Grande Valley. The North Floodway empties into Laguna Madre about 14 miles south of Port Mansfield. However, the volume of water carried is normally very low (Breuer, 1962). The Arroyo Colorado is a floodway carrying drainage and excess rain water from parts of the Rio Grande Valley watershed. There is no other source of fresh-water (or sediment) streamflow into south Laguna Madre. Except in times of

Table 1. Rainfall distribution (in inches) Raymondville, Texas

	1953	1954	1955	1956	1957	1958	1959
January		0.26	1.58	0.03	0.05	7.33	1.44
February		0.09	0.37	1.23	2.55	3.91	2.69
March		0.55	0.03	--	2.57	0.71	0.13
April		4.07	0.16	4.32	3.23	0.23	1.20
May		2.27	5.61	2.76	2.14	1.77	2.15
June		2.87	0.30	1.05	4.66	2.17	1.43
July		0.21	4.03	0.04	0.56	3.27	0.46
August		1.27	2.79	1.20	0.30	--	
September	0.35	4.05	15.90	2.21	1.50	4.44	
October	1.95	3.74	1.16	0.64	1.30	10.94	
November	3.46	1.69	0.63	0.47	3.48	1.80	
December	0.84	0.11	0.57	1.00	0.11	1.25	

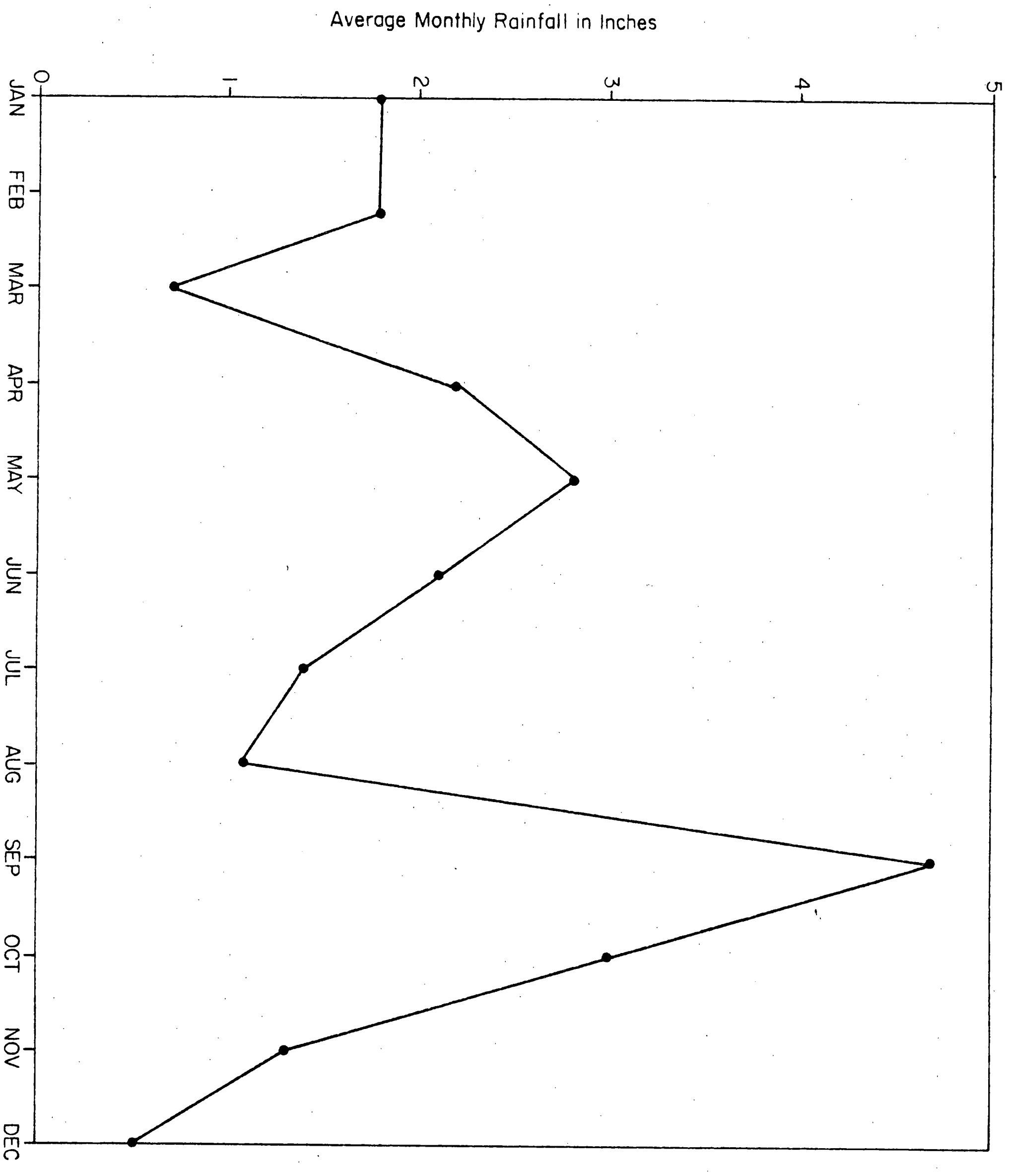


Figure 2. Histogram of rainfall distribution for Raymondville, Texas area, 1953-1959. Data after Breuer, 1962.

flooding, the amount of fresh-water discharge into the study area must be considered negligible (Breuer, 1962).

Wind data were also taken from the Raymondville Weather Station for the years 1953-1959 (Breuer, 1962). The wind blows from the southeast 52 percent of the time. Percent of time the wind blows in other quadrants is as follows: south-southeast 28 percent of the time, northwest 7 percent, north-northwest 7 percent, east-southeast 3 percent, and 1.5 percent each from the east and south. A wind rose diagram (taken from McGowen, 1977) of relative wind dominance (fig. 3) shows that the majority of geologic and hydrologic work is accomplished by southeast and south-southeast winds. The current resulting from the predominance of these winds affords excellent exchange of water through the Lower Laguna Madre (Breuer, 1962).

Available data on astronomical tides in Lower Laguna Madre were sparse at best. Fisk (1959) states that tidal variations in the Laguna Madre were small in 1948 (just before dredging of the ICWW). Mean annual tidal range in Redfish Bay, just north of the study area, was 0.35 foot whereas Port Isabel to the south recorded 1.24 feet. In 1948 the southern Laguna Madre tide gage recorded a maximum elevation of 2.4 feet above sea level in June, and a minimum elevation of 1.15 feet below sea level in November; these maximum and minimum elevations reflect the effect of persistently strong wind action. Breuer (1962) states that daily effect of the tide decreases away from Brazos Santiago Pass. Furthermore, water circulation is usually controlled by wind tides, which pile water up on one or another of the lagoon margins. Spring and

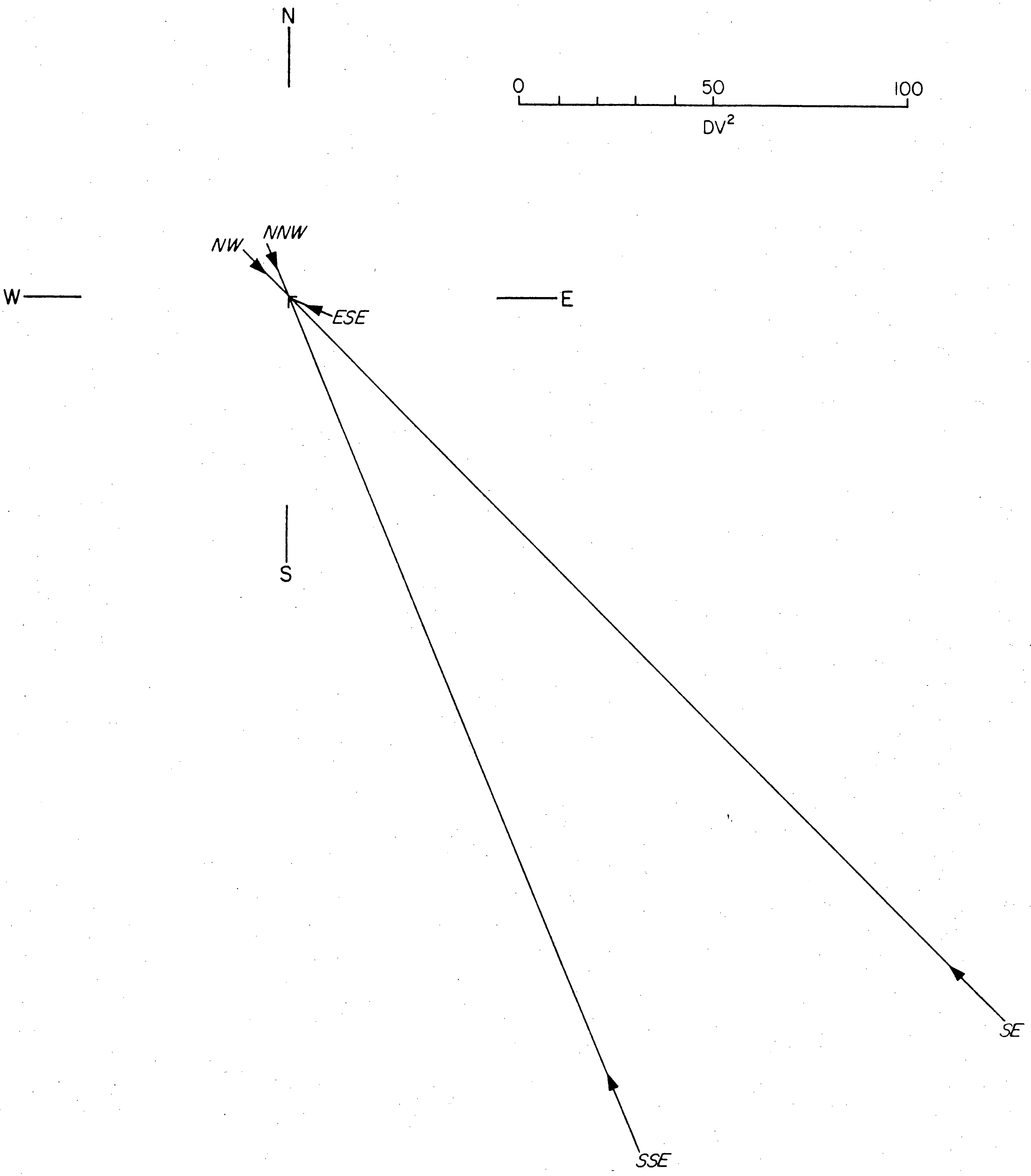


Figure 3. Wind rose for Raymondville, Texas area, showing wind dominance (WD = DV^2). Data after Breuer, 1962.

fall celestial tides can raise the water as much as 1.5 feet, whereas lunar tides are small with measured fluctuations of 1 to 2 inches.

Water circulation for southern Laguna Madre is detailed by Breuer (1962). In general, in a southeast wind, Gulf water of 32-35^{o}/oo enters Brazos Santiago Pass and flows north toward the Kenedy Land Cut. The effect of Mansfield Pass is to serve as a "valve" to the circulation system. Excess water pushed upon the narrow Land Cut area (width across the lagoon here is essentially that of the width of the ICWW, about 125 feet) from southern extremities of the lagoon are able to flow out through Mansfield Pass into the Gulf, thereby reducing the "head" built up in Redfish Bay. Only during periods of north winds is the circulation system reversed.

FIELDWORK

Bottom sampling, on a one-half mile grid, was conducted from March through April 1977. Three hundred and eight bottom samples were taken from an Airboat. The position of sample stations was determined by resection; bearings were shot from each station with a Brunton compass using known land features and Intracoastal Waterway markers. Bearings were recorded in field books and map locations were plotted on Nautical Chart No. 11303 (scale 1:40,000). Samples were taken with a posthole digger over the gunwale of the Airboat. Depth markers on the posthole digger handles supplied depth readings at each station. Each sample was described, and location, water depth and time of day were recorded. Subsamples were taken for texture, trace element geochemistry, foraminifera, and storage. The remaining sediment was then poured into a wash bucket with a 1-mm mesh screen bottom and washed until only biologic constituents remained. Shell content, worm content, and flora (seagrasses and algae) were then described before contents were bagged and put in an epsom salt and seawater solution. Biological contents, primarily invertebrates, were later transferred to a formaldehyde and Rosebengal with borax solution for preservation.

Vegetative mapping is based primarily on identification made in the field at the time each sample was taken. Field calls for taxonomy of seagrasses were based primarily on leaf-tip and leaf-blade morphology. This means of identification was recommended by Dr. Calvin McMillan, University of Texas at Austin, Department of Botany as a reliable and feasible means of identification for field or laboratory purposes. Any questionable data were checked in the lab before mapping to verify taxonomy and/or density. Algae were also identified so as to complete floral systematics. Algae were keyed using Peter Edward's guidebook "Seaweeds and seagrasses of the Texas Coast" (1976). Seagrasses, in addition to being classified, were checked for evidences of flowering and seeds; neither were observed. Density was classified qualitatively as dense, moderate, sparse to void by visual estimate at the time each sample was taken. When water was too turbid an estimation was made based on the amount of rooted seagrass in the washed biological sample. Qualitative evaluations were necessary because of the nature of the fieldwork involved.

GENERAL DISCUSSION OF SEAGRASSES

Species Occurring on Texas Gulf Coast; Speices Encountered in Study

There are five species of marine spermatophytes on the Texas Gulf Coast These are: *Halodule wrightii, Syringodium filiforme, Halophila engelmannii, Ruppia maritima,* and *Thalassia testudinum.* Live species (rooted, viable) observed in the study area were *H. wrightii, S. filiforme, H. engelmannii,* and *R. maritima. T. testudinum* was only found as floating or bottom debris.

In the past two decades several relevant papers have been published on seagrass systematics and ecology of the Texas Gulf Coast species. Hoese (1960) and Edwards (1976) worked on seagrasses in the Port Aransas area. McMillan and Moseley (1967) reported salinity tolerances and taxonomy of seagrasses from the Texas Gulf Coast. Simmons (1957) identified algae in Upper Laguna Madre and determined the effect of salinity on them. The Texas Parks and Wildlife Department has several reports of relevance which are as follow: Singleton (1964), McMahan (1965, 1966, 1968), and West (1969, 1971a, 1971b, 1972, 1973). Breuer (1962) made reference to the general occurrence of seagrasses in his report on the general ecology and hydrology of Lower Laguna Madre. Cornelius (1975) studied the seagrasses and invertebrates of Lower Laguna Madre in regard to their food value to wintering ducks. References considered relevant to seagrass systematics, ecology, and distribution for the Texas Gulf Coast are in the bibliography of this report.

Taxonomy of the 4 species encountered in this study as well as *T. testudinum* are covered by Edwards (1976) as follows:

Order: *Hydrocharitales*
    Family: *Hydrocharitaceae*
        Genus/specie: *Halophila engelmannii*
            Thalassia testudinum ("Turtlegrass")

Order: *Najadales*
    Family: *Potamogetonaceae*
        Genus/specie: *Syringodium filiforme* ("Manateegrass")
            Halodule wrightii ("Shoalgrass")
            Ruppia maritima ("Widgeon grass")

Morphological characteristics of each seagrass is listed under the illustration of each from den Hartog (1970). Primary means of identifying seagrasses for this study was recognition of leaf-tip morphology and leaf-blade configuration (fig. 4).

Salinity tolerance, perhaps the most significant environmental factor controlling seagrass ecology, was studied in detail by McMillan and Moseley (1967). A general (brief) discussion of their results is presented. *Halodule wrightii* was found to be the most tolerant of high salinity. Plants placed in increasing salinity continued to show leaf elongation throughout their study, suggesting a broad tolerance of salinity. *Thalassia* growth rates in increasing salinity suggested lesser salt tolerance than that of *H. wrightii.* Many segments of *Thalassia* did not survive up to 60^{0}/oo, but some persisted in salinities as great as 74^{0}/oo. The percent of survival for *Thalassia* at the

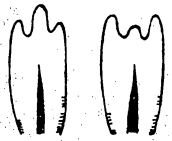
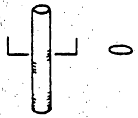
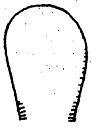
Hadodule wrightii		serrated leaf tip tannins (as seen under microscope)
Syringodium filiforme		round leaf blade
Halophila engelmanii		rosette of elliptical leaves
Ruppia maritima		"needle" or sharp (not serrated) pointed tip
Thalassia testudinum		rounded leaf tip; flat wide leaf blade

Figure 4.

highest salinity was considerably less than for *Halodule*. *Ruppia* testing suggested that it can tolerate a salinity concentration as great as 74^{0}/oo (at least for brief periods). Due to inconsistent responses to high salinity, McMillan and Moseley suggested that *Ruppia* may be less tolerant of high salinity than *Thalassia*. *Syringodium's* growth responses suggested it had the <u>least</u> salinity tolerance of the 5 seagrasses. Growth terminated at 45^{0}/oo salinity in a controlled room situation, suggesting some inhibitory action by brine water. Chlorophyll data obtained in the experiments indicated that *Syringodium* did not tolerate waters greater than 60^{0}/oo salinity (*Syringodium* had less chlorophyll per gram than any other species studied). *Halophila* showed sporadic occurrences at high salinities suggesting that its salinity tolerance was greater than that of *Syringodium* (however, McMillan and Moseley found it was not possible to compare it with the other 3 species). Thus, the following order of decreasing hypersalinity tolerance was suggested by their study: *Halodule, Thalassia, Ruppia, Syringodium*. *Halophila's* tolerance was indefinite, but is probably less tolerant of hypersalinity than *Halodule* but more tolerant than *Syringodium*. An important emphasis made by their study is that survival at extremely high salinities for extended periods of time would not be expected. The solubility of a given salt in the presence of other salts varies in relation to changing concentration in evaporating seawater. According to Copeland (in McMillan and Moseley, 1967) Fe_2O_3 and $CaCo_3$ tend to precipitate at salinities approaching 70^{0}/oo. McMillan and Moseley concluded that since their study showed most plant activity ceased at about 70^{0}/oo that it seemed likely that changes in salts could have impaired plant (seagrass) growth at high concentrations.

MAPPING

Mapping of seagrass distribution and density was undertaken in April and May of 1977 and again in March and April of 1978. Nautical chart 11303 (scale 1:40,000) was chosen as a base map because of its large scale representation of features within the study area and previous mapping in this area was compiled on a 1:40,000 base. Postplots of sample localities were transferred from the field map to the 1:40,000 base map. Data from the field description sheets were then transcribed onto respective base maps for: sediment distribution, bathymetry, total organic carbon, 29 trace elements, and seagrass density/distribution; all were mapped at scale of 1:40,000.

Mapping of seagrass density and distribution was approached from the perspective of revealing any significant trends and/or changes since the Parks and Wildlife 1961 map by J. L. Pipkin, Jr. for Singleton (1969). Data from field descriptions on density and occurrence at each sample station for *H. wrightii*, *R. maritima*, and *H. engelmannii* were transferred onto a 1:40,000 base map then contoured. Density classes of rooted seagrasses were used as the basis for contouring [(1) dense, (2) moderate, (3) sparse to very sparse with areas void of vegetation were so marked]. The same was done (on a respective base map) for *S. filiforme*. *R. maritima* and *H. engelmannii* were grouped with *H. wrightii* due to their rare occurrences versus the ubiquitous occurrence of *H. wrightii*.

A map of gross seagrass distribution and density (all four species) for the entire study area was also prepared at a scale of 1:40,000.

Mapping by the Texas Parks and Wildlife Department was the only source of comparative mapping available. The Parks and Wildlife mapping was initiated in 1960-1961 under Job #17, Federal Aid Project #W-29-R-14; Survey, Coastal Waterfowl, "Ecology of the Principal Waterfowl Food Plants of the Lower Laguna Madre," J. R. Singleton, Project Leader. Objective of the mapping was to determine plant species, present location and approximate acreage of each. Under calm surface conditions and clear water, rooted vegetation was estimated by eye and density values from 100 percent to 0 percent were assigned (otherwise an estimate was made based on the grab sample). Sampling transects were run on azimuths of 60° and 240° from Intracoastal Waterway markers (note: many of the ICWW markers Parks and Wildlife used were even numbered and were apparently discarded and relocated after the 1960-1961 study, therefore locations are approximate after transferring data from their 1961 map onto the 1:40,000 base map). The transects run by Parks and Wildlife were approximately 1/3 mile apart E to W and approximately 3/4 mile apart N to S. Fieldwork and mapping for the initial study was conducted by James L. Pipkin, Jr. (Asst. Project Leader).

A second study, funded by Federal Aid Project #W-29-R-18, was made by Parks and Wildlife in 1965, led by C. A. McMahan; data from this study are contained in a New Mexico State University Master's thesis (1969). The fifteen selected transects mapped by Pipkin were reoccupied by McMahan in 1965 for purposes of documenting any changes in density and distribution of seagrasses in the Lower Laguna Madre. McMahan revised the Parks and Wildlife method of "density classes" by combining Pipkin's units into broader groups. Selected transects were reoccupied in June and July of 1966, using the 1965 techniques. Maps were made depicting changes in seagrass density and distribution for selected transects. Parks and Wildlife continued to monitor changes via reoccupation of "permanent vegetative transects" in Laguna Madre until 1972; data on their findings is sparse and inconclusive. "Permanent" Parks and Wildlife transects in the Lower Laguna Madre exclude the study area as they are located in Port Isabel Bay (1-transect) and Redfish Bay (1-transect just south of Mansfield Pass). Findings were reported for changes occurring from 1968-1969, 1969-1970, 1970-1971, 1971-1972. Map #4 "Density of seagrasses, southern Laguna Madre, Texas, 1961" is a "translation" of the data presented on the 1961 Parks and Wildlife map by Pipkin (in Singleton, 1964). ICWW markers and Parks and Wildlife transects were transferred onto the 1:40,000 base map. The locations are approximate. Data on seagrass distribution and density at each station along each transect were then plotted on the 1:40,000 base. Contouring was based on McMahan's "reorganization" of Pipkin's percentage units into stands of: dense (100-70 percent), moderate (70-42 percent), light to sparse (42-19 percent), and areas void (0 percent) of vegetation. Pipkin's fieldwork in 1961 revealed the presence of only two species within the study area, *Halodule wrightii* and *Ruppia maritima*.

Bathymetry for the area was displayed by 0.25-foot contours. Field descriptions were utilized to map surface sediment distribution. Distribution of total organic carbon, preliminary molluscan assemblages and trace metals, although not a part of this study, have been mapped as a part of the Bureau of Economic Geology's State Submerged Lands Project (McGowen and Morton, 1977; McGowen and Morton, in press).

RECENT CHANGES IN SEAGRASS DISTRIBUTION AND DENSITY REVEALED BY COMPARATIVE MAPPING

Parks and Wildlife Department maps (Pipkin, in Singleton, 1964) show the general distribution of seagrasses in the study area during 1960 to 1961. Parks and Wildlife encountered only 2 species at this time--*Halodule wrightii* and *Ruppia maritima*. Areas void of vegetation occur most frequently where the bottom is periodically emergent because of wind-tidal activity. Seagrasses should be expected to survive complete emergence only very brief periods. Scattered localized barren spots are present east of the ICWW. They are interpreted to be small and, according to Parks and Wildlife Department, caused by the "rooting" activity of the black drum (*Pogonias eromis*). The 1961 map reveals a "banded" distribution for the lagoonal waters east of the ICWW. Banding is probably a function of water depth. As water depth increases from the bay shoreline of South Padre Island westward to the ICWW so does the density of seagrasses. Depth apparently was a very important control on distribution and density of seagrasses in 1961 (although no bathymetric map was available it is assumed that bathymetry in 1961 was similar to our mapping for 1977). *Rupia maritima* is mapped as occurring most often on the west side of the ICWW adjacent to spoil mounds between flasher "29" and can "19," in the area of Three Islands (from flasher "39" to "29") to the east of the ICWW, adjacent to Rattlesnake Island (west of ICWW), and from flasher "316" to the northern limit of the study area, surrounding spoil mounds west of the ICWW. All reported occurrences of *R. maritima* were listed as dense stands. No *R. maritima* was found (i.e. reported) anywhere more than 0.25 mile east of the ICWW in 1961.

Halodule wrightii, the only other seagrass reported in the 1961 study for this area, covered the major part of the lagoon bottom. Density of *Halodule* increases directly as water depth and distance from both bay shorelines increase. *Halodule* is present as dense pure stands and as dense mixed stands (with *Ruppia*). Dense stands are present (1) from Gabrielson Island to the tip of El Realito Peninsula on the mainland margin, (2) in association with dense *Ruppia* surrounding spoil mounds west of the ICWW from flasher "29" to can "19," (3) surrounding Rattlesnake Island in a mixed stand with dense *Ruppia*, and (4) from flasher "316" to the northern limit of the study area surrounding spoil mounds west of the ICWW. A continuous dense band of *Halodule* parallels the ICWW (and to the east) from the southern to the northern limits of the study area. The band reaches a maximum eastward extent (from the ICWW) of about 3 miles, and averages about 1 mile in width to the east of the ICWW. There are moderate stands of *Halodule* west of the ICWW from flasher "59" to Caballo Island where it surrounds spoil mounds. Moderate stands are also adjacent to the previously mentioned dense stands of *Ruppia* to the west of the ICWW. East of the ICWW moderate stands of *Halodule*, like the dense stands, run continuously for the length of the study area. Light to sparse stands of *Halodule* parallel the mainland margin and bay shoreline of South Padre Island. The light to sparse concentrations are discontinuous along the mainland shoreline as they are interrupted by barren spots and by denser concentrated stands.

Vegetation mapping by Parks and Wildlife Department is useful and relevant. However, their base map was defective with respect to readability and locations of ICWW markers; location of transect lines and sample stations are approximate. It is the earliest vegetative map of the area and is useful despite its shortfalls.

McMahan's 1965 and 1966 reoccupation of the 1961 transects showed marked changes. A transect off of flasher "39" showed that a dense stand of *R. maritima* near the mainland margin had been replaced by a light stand of *H. wrightii* between 1961 and 1965. Similarly, dense stands of *Ruppia* just west of flasher "19" and flasher "306" were replaced by a dense stand of *Halodule* (surrounding a line of spoil islands west of the ICWW) during the span from 1961 to 1965. McMahan's subsequent mapping indicated that the area to east of the ICWW (off of flashers "39," "19," "326," and "306") was characterized by almost constant density of *Halodule* during the interim period. However, colonization of areas that were barren in 1961 documents the fact that *Halodule* increased its bottom coverage between 1961 and 1965. McMahan's results showed that *Syringodium* was expanding northward in Port Isabel Bay, just to the south of the study area. In 1965, however, apparently no *Syringodium* had yet encroached upon the study area (based on McMahan's mapping). *Ruppia* had decreased in the study area, and McMahan reported that stands found in 1961 from Port Isabel to Port Mansfield had all decreased and/or been replaced. It should be noted that in 1962 Breuer indicated that 3 species of seagrasses in Lower Laguna Madre had extended their range northward--*Halodule* northward to the upper extremity of the lagoon, *Syringodium* to the Three Islands area, and *Ruppia* to South Redfish Bay (along spoil dumps).

McMahan's study in 1966 revealed significant changes in species distribution. Reoccupation of transects in Lower Laguna Madre showed the marked northward expansion of *Syringodium*, such that by 1966 *Syringodium* had not only colonized the study area but had also encroached upon South Redfish Bay. McMahan's 1966 report shows that stands of *Syringodium* observed in the study area (in the Three Islands area specifically) increased in density and area (localized) during 1966. *Ruppia* by this time had been reduced to a few small, sparse stands in the study area. *Halodule* remained relatively unchanged in distribution and density. *Thalassia* remained largely confined to a few shoal areas in Port Isabel Bay and did not show any change from the 1961 survey. McMahan states that "*Halophila engelmannii* grew in small widely scattered associations (through Lower Laguna Madre) and was not measured in terms of relative abundance." Therefore no firm conclusions can be drawn as to changes in *Halophila* for the period 1961 to 1977.

Parks and Wildlife Department studies, subsequent to the work of McMahan (1966), are largely inconclusive and too brief. The study area was excluded from annual "reoccupation" (of "permanent vegetative transects"); monitoring during the 1968-1973 period was restricted to a transect just south of Port Mansfield and a transect in Port Isabel Bay. If any changes transpired between 1966 and 1968 they were not recorded (or the reports were not available to me) and the seagrass-monitoring project was terminated in 1973. Results of the interim study from 1968 to 1973 are presented herein as there is no other source of available data. From 1968 to 1969 long-term vegetative transects in Lower Laguna Madre indicated little significant change in species composition; however, the total bottom cover definitely increased. The period 1969 to 1970 indicated little significant change in species composition although the total bottom cover showed definite fluctuations (Parks and Wildlife Department states these may be normal cyclic changes rather than significant trends). Data gathered during 1970 to 1971 showed little significant change in species composition and no significant change in bottom cover. Results for the interval 1971 to 1972 were the same as for 1970-1971. A comparison of 1972 and 1973 data show no significant changes. There are no data for the period 1973 to 1977.

Significant changes in species composition, distribution, and density are obvious when the 1961 and 1977 data are compared. The 1961 base was used for comparison because it is the only detailed base map that was available from Parks and Wildlife. McMahan's thesis includes a map that displays seagrass distribution in 1965 for the entire Lower Laguna Madre, but scale is not sufficient for detail, and it is basically the same as the 1961 base. A comparison between my mapping and that of Parks and Wildlife Department is relative because my observations were qualitative whereas Parks and Wildlife Department data were quantitative.

When the 1961 Parks and Wildlife Department base and the 1977 "Density of Seagrass Distribution" maps are compared, some significant trends can be perceived. At the time fieldwork was conducted for the present study (March and April 1977) the southern part of the study area, to the east of the ICWW and south of Three Islands, was still characterized by moderate to dense stands of seagrasses. Density, south of Caballo Island and west of the ICWW, changed somewhat as the bay (El Realito Bay) between El Realito Peninsula and Hobnail Island changed from light to sparse into a dense stand of seagrass. Areas adjacent to points JM37.5, JM61.5, and JM62, which were barren in 1961, showed sparse to moderate stands of seagrass in 1977. The area adjacent to Medio Island and the spoil mounds to the south was mostly unchanged. In the area between Three Islands and Green Island (east of the ICWW) seagrass density seems to have changed from a "banded" configuration in 1961 to one in 1977 where moderate stands of seagrass are now within 0.50 to 0.25 mile of the bay shoreline of South Padre Island. It is not possible to state whether or not the change from Parks and Wildlife Department's "banded" configuration to the 1977 configuration of discontinuous density distribution is valid or is due to the aforementioned differences in field interpretation of density. The area east of the Arroyo Colorado Cutoff Channel (and the ICWW) and adjacent (parallel) to the General Land Office-NOAA tide gages appears to have shown marked change both in an increase in density and in species composition. Density and extent of seagrasses have increased just south of Green Island where moderate stands now grow relatively close to South Padre Island's bay shoreline. Between 1961 and 1977 the lagoonal segment from Green Island to the northern limit of the study area has experienced expansion of the bottom cover. Dense stands are now within 1-2 miles (west) of the island's bay shoreline, whereas in 1961 dense stands straddled and paralled the ICWW only. Moderate stands have apparently increased their extent to within 0.25 mile of the island shoreline, although at the northern boundary the grasses start to decrease in density close to the shoreline near points JM290, 308, 313.

West of the ICWW from Three Islands to the Arroyo Colorado Cutoff Channel several significant changes have occurred. 1977 mapping reveals that the dense stands of *Ruppia maritima* and *Halodule wrightii* surrounding spoil mounds from flasher "29" to flasher "19" in 1961 have been reduced to primarily sparse stands in 1977. The area surrounding Rattlesnake Island has changed markedly since 1961 when dense stands of *Ruppia* and *Halodule* surrounded all but the western tip of the island. In 1977 only sparse stands of *Halodule* with no *Ruppia* remained. The western tip of Rattlesnake Island, void of any vegetation in 1961, showed sparse colonization by *Halodule* in 1977. The small mainland area just west of ICWW mile marker 645 showed that *Halodule* spread from being adjacent to the ICWW in 1961 to the mainland shoreline in 1977 (although stands were very sparse). The area west of the ICWW from flasher "316" to the northern limit of the study area was not mapped as of this writing, but based on tentative field observations has not changed dramatically from the 1961 mapping.

1977 field observations were used for derivative mapping of *Halodule, Syringodium,* and *Halophila* species distribution and density for the study area. *Ruppia* was notated on the *Halodule* map due to its limited occurrence and its association with *Halodule* in mixed stands; *Halophila* was presented with *Halodule* due to its infrequent occurrence. Using the previously stated results of the Parks and Wildlife Department's mapping from 1961 to 1973 of species distribution and density, one can ascertain the changes that occurred from 1961 to 1977. The 1977 map of species distribution and density show dramatic changes when compared to the 1961, 1965 and 1966 Parks and Wildlife Department's results. *Halodule*, the sole vegetative type for (with 99 percent of the bottom cover mapped) most of the area east of the ICWW in 1961, shows marked decrease in its distribution and density in 1977. As revealed by the distribution map of *Halodule* (and *Ruppia*) large "holes" are present where *Halodule* once existed in sparse to dense stands. When distribution of *Syringodium* and *Halodule* are compared it is readily apparent that *Syringodium* is encroaching upon and in many areas totally replacing *Halodule*. In places the two grasses exist in mixed stands as well as being in separate and distinct stands. When seagrasses occur in mixed stands normally only two will be present and one will be dominant. In several locations though, two seagrasses (such as *Syringodium* and *Halodule*) may occur in moderate to dense concentrations within one mixed stand.

The map of 1977 *Halodule-Ruppia-Halophila* distribution and density reveals that *Halodule* still cover at least 70 percent of the submerged lands of the study area in very sparse to dense stands. West of the ICWW *Halodule* has decreased in total bottom cover and density since 1961. Since no data are available for the interim years (1961-1977), no conclusions have been drawn. In general, the occurrence and density of *Halodule* are sporadic. Many of the areas that in 1961 supported sparse to dense *Halodule* showed only dead *Halodule* debris covering the bottom in 1977. Since penetration of the posthole digger was sufficient to have pulled up any rooted plants in addition to the bottom debris, it was assumed that the bottom was void of any significant live vegetation where none was mapped.

East of the ICWW and south of Three Islands to the northern limit of the study area *Halodule* is "patchy." As compared to the 1961 map, *Halodule* distribution has changed from continuous "bands" covering the length of the study area to patchy stands. Density of stands has also decreased significantly. Only 3 stands of *Halodule* were mapped as being fairly dense, and their respective areal distribution was relatively small and localized. Moderate stands of *Halodule* were more numerous in occurrence, but again they too were small and localized. Of the 70 percent or so of bottom area covered by *Halodule* in 1977 at least 80 percent of the area was characterized by very sparse to sparse stands.

1977 distribution and density of *Syringodium* indicates marked encroachment upon the study area as compared to previous mapping. Since 1965 *Syringodium* has encroached upon and in places replaced *Halodule*. No physical data were available for the interim years, but several causes cited in the conclusions to this report may be speculated upon as having been at least partly responsible for the increased northward expansion of *Syringodium* (from being present only in Port Isabel Bay in 1961 to being present as far north as southern Redfish Bay in 1977).

Syringodium west of ICWW is sporadic and is generally sparse to very sparse. El Realito Bay showed a significant colonization by *Syringodium*. Bottom cover in 1961 consisted of light to very sparse *Halodule*, whereas in 1977 only *Syringodium* in moderate to dense (increasing in density toward the head of the bay) stands populate the bay. Thus *Syringodium* at some time in the past encroached upon a light to very sparse colony of *Halodule* and by 1977 had totally replaced it. The area adjacent to points JM10 and 14 supports a sparse to dense (dense around JM10) stand of *Syringodium* where only light to sparse *Halodule* occurred in 1961. *Syringodium* also occurs in sparse to very sparse stands adjacent to Medio and Caballo Islands as well as just west of the ICWW spoil mounds near flashers "19" and "9."

East of the ICWW *Syringodium* has shown a tremendous colonization of an area where none occurred in 1961. *Syringodium* occurs in a continuous band of very sparse to dense concentrations from the southern limit of the study area as far north as Rattlesnake Island (or just past flasher "19"). This "band" parallels the deeper areas of the lagoon indicating that it is depth dependent and occurs in moderate to deep waters. Sections of the "band" coincide with stands of *Halodule* and also border occurrences of *Halophila* (discussed later). Stands of sparse to dense *Syringodium* occur sporadically from flasher "9" to the northern boundary of the study area. Within this area though, an east-west aligned continuous stand of dense *Syringodium* occurs off the mouth of the Arroyo Colorado Cutoff Channel and parallel to the General Land Office-NOAA tide gages. This stand was not observed during field work in April, 1977, but was observed during a "walkout" in July, 1977 through this section of the lagoon. This stand occurs in association with sparse to moderate *Halodule*. Also, near JM181 a moderate (small) stand of *Ruppia* was observed growing on a spoil mound in association with moderate to dense *Syringodium*. North of Green Island *Syringodium* again shows depth dependency as it occurs only in water greater than 1.5 feet (generally in water 1.75 feet to 2+ feet). A continuous band runs from about flasher "321" to flasher "311" (almost 4 miles from south to north). In some areas it is mixed with stands of *Halodule* (sparse to dense).

Ruppia, though mapped by Parks and Wildlife Department in 1961 (and subsequent studies), was insufficient in occurrence to warrant a "separate" map of distribution and density. It was therefore notated on the map of *Halodule* where it occurred by itself or in mixed stands. Occurrences of *Ruppia* in 1961 were cited in the first part of section VI. *Ruppia* was found in only 2 distinct and localized areas during the 1977 field study. The first was an aforementioned moderate to dense stand on and adjacent to a submerged spoil mound near JM181. The second was near JM275 where it occurred in a mixed stand with moderate *Halodule* and dense *Acetabularia crenulata* (fig. 5). Both stands were healthy, rooted, and grew to within a few inches of the water surface. The distribution of *Ruppia* has changed since 1961.

In 1977 the distribution of *Halophila* was sporadic and localized. Only two occurrences were observed west of ICWW. Sparse to very sparse stands were at stations JM10.5 and at JM63. At JM10.5 *Halophila* occurred by itself, whereas at JM63 it was in a mixed stand with sparse *Halodule*. East of the ICWW distribution was again limited. A continuous stand (1.5 miles in length N to S) of very sparse to moderate *Halophila* occurred just east of Primero Island. The southern most part of this stand was mixed with sparse *Halodule* while the rest was distinct. The only other spotting of *Halophila* was that of a sparse localized stand at JM89 where sparse *Halodule* also grew. Parks and Wildlife Department did not map *Halophila* because of its sporadic and limited occurrence. Therefore, no conclusions can be drawn as to changes in distribution and density from 1961 to 1977.

CONCLUSIONS

Seagrasses encountered in the southern Laguna Madre study area during March through April 1977 included (in order of abundance): *Halodule wrightii, Syringodium filiforme, Halophila engelmannii,* and *Ruppia maritima.* No *Thalassia testudinum* was found that was rooted or viable in the study area during the stint of fieldwork involved. In addition to the four marine spermatophytes, two species of algae were observed in many areas. *Laurencia poitei,* a red alga (division: *Rhodophycophyta*), was abundant in most of the lagoon east of the ICWW. The reddish to green (fig. 6) alga was most commonly in "drifts" or clumps, and rarely was attached to the bottom. It occurred alone in scattered "patchwork" stands or in association with seagrass. *Acetabularia crenulata,* a green alga (division: *Chlorophycophyta*) was abundantly distributed throughout the study area east of the ICWW. This green alga was rooted in numerous locations (in both deep and shallow water) and in other places it accumulated in "drifts" or clumps of non-attached debris (see fig. 5). *Acetabularia* locally, and in particular the Green Island area, grew in thick-dense stands. These stands of *A. crenulata,* as well as *L. poitei,* could be mis-identified as "grassflats" from high or low altitude aerial photos (fig. 7).

Major changes for the period 1961 to 1977 as revealed by comparative mapping of the study area include the following:

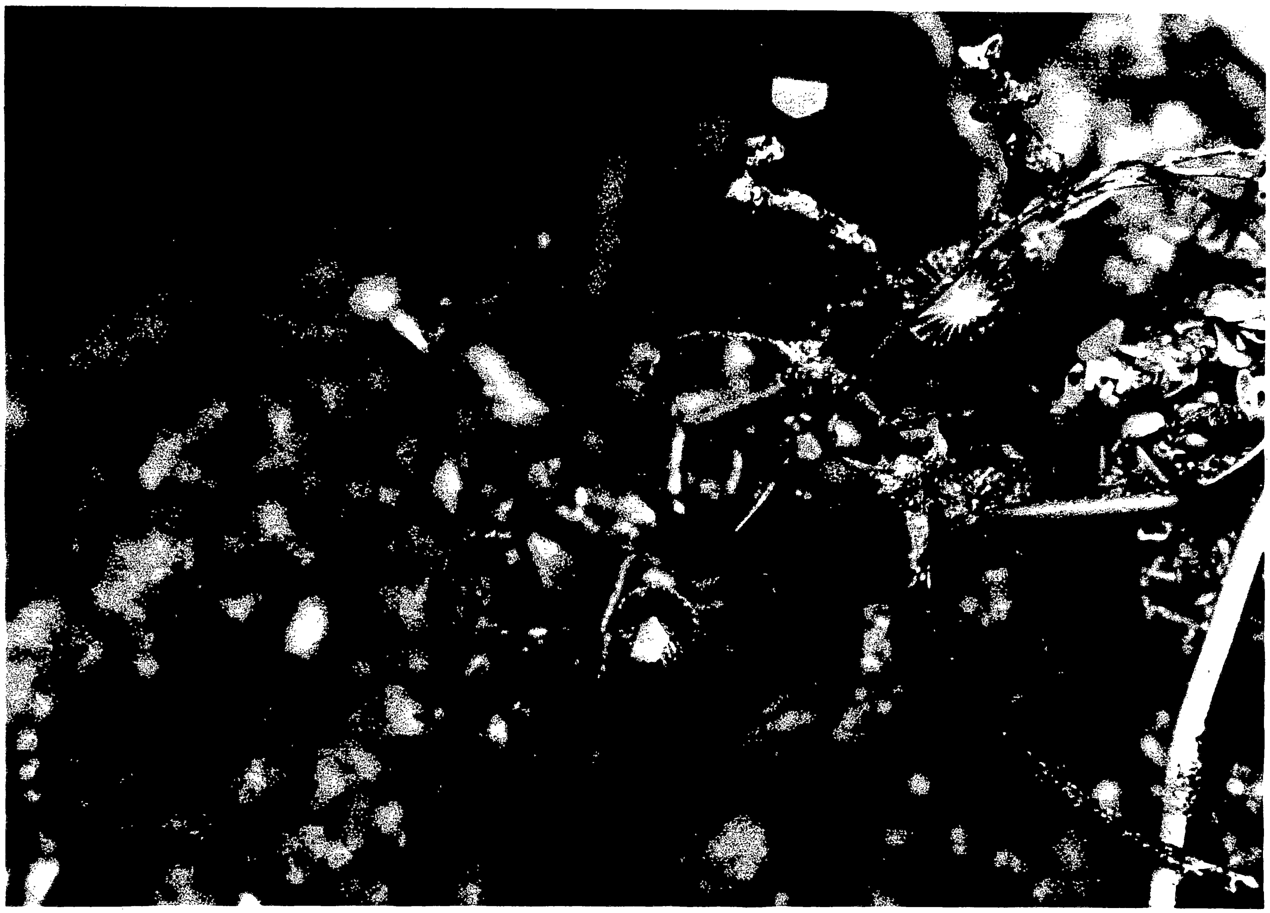


Figure 5. Locality is JM275. *Ruppia maritima* mixed with *Halodule wrightii* and *Acetabularia crenulata*.

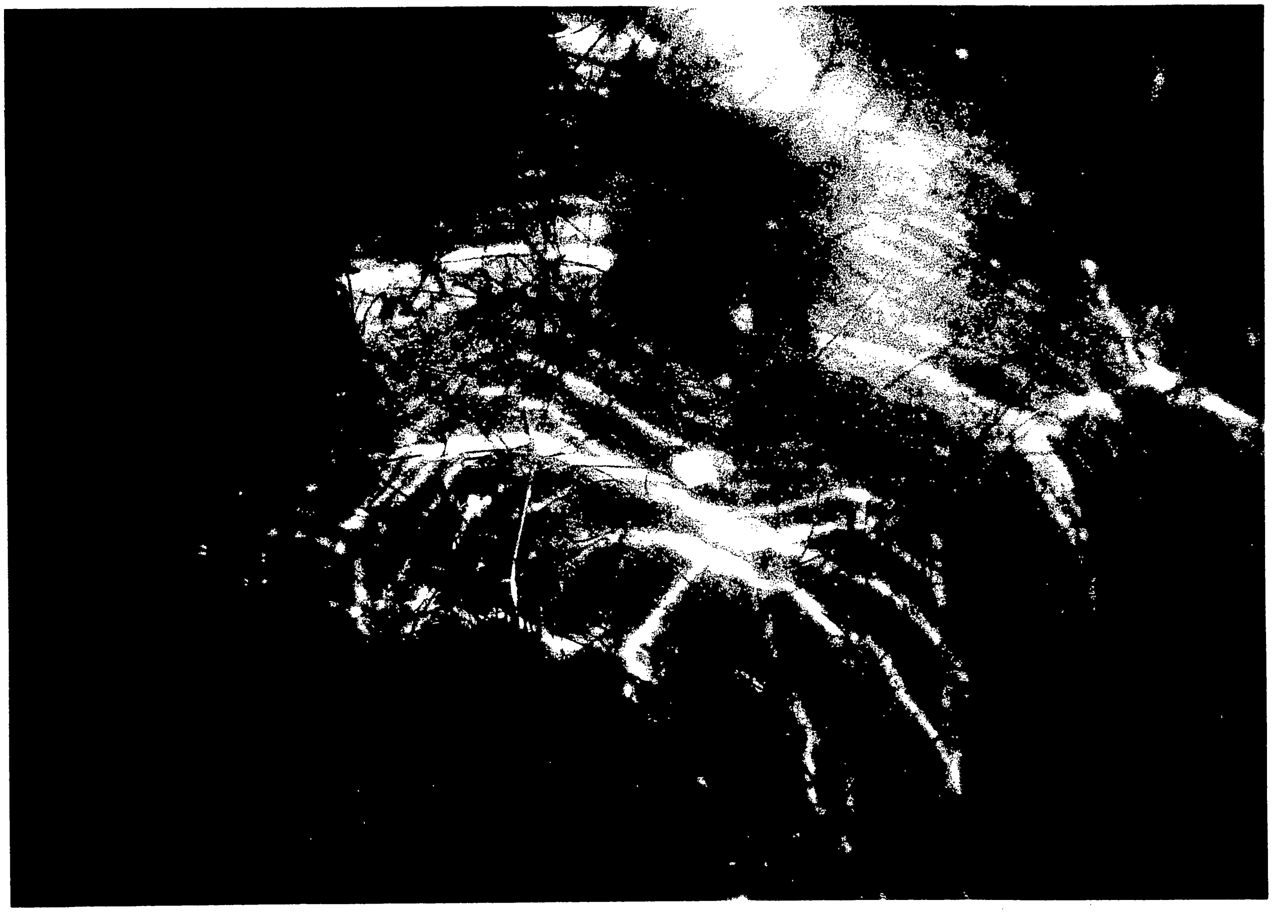


Figure 6. *Laurencia poitei* (red alga) in association with *Halodule wrightii*. *Laurencia* is the club-shaped plant.

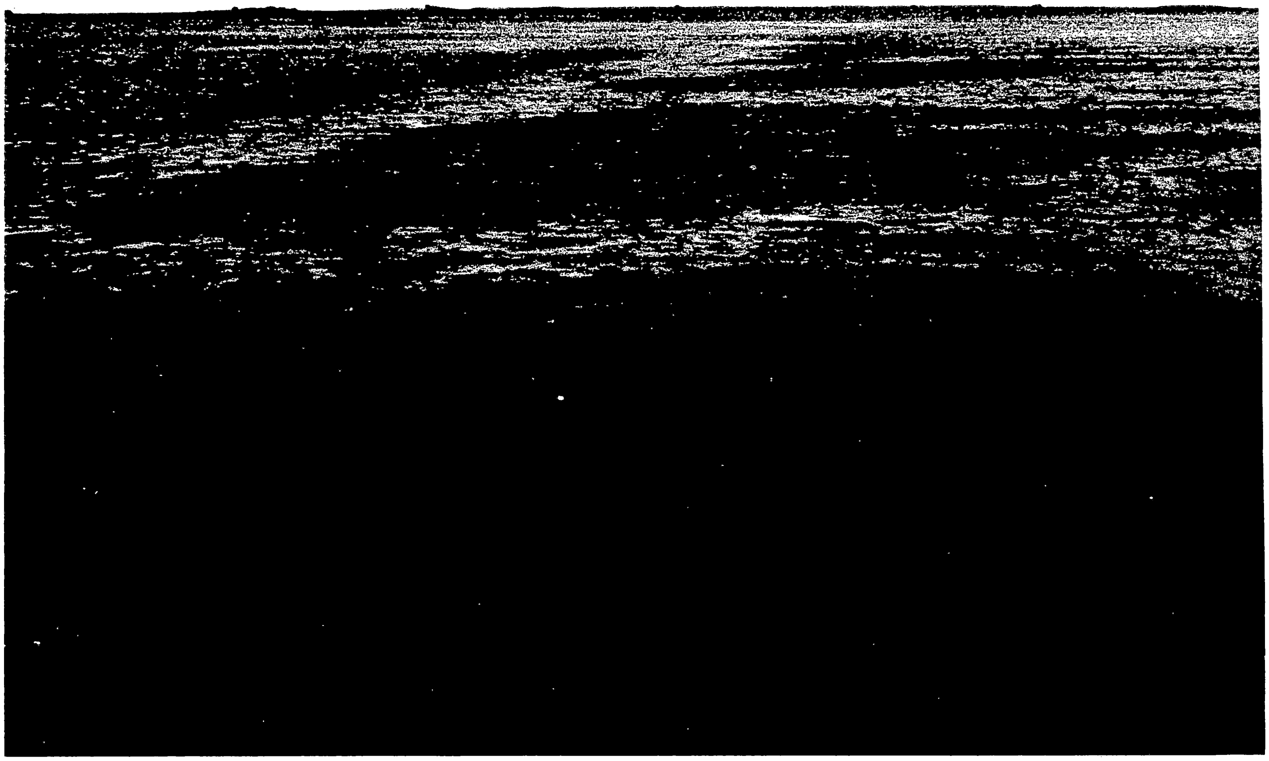


Figure 7. View of submerged vegetation in the Green Island area. Some dark patches are "grass flats" while others are "algal flats."

1. Decrease in total bottom cover of *Halodule* as well as a decrease in density of stands. In 1964 Singleton reported only the presence of *Halodule* and *Ruppia* within the study area. As late as 1966 *Halodule* was still the dominant seagrass in the lagoon east of the ICWW.
2. Increase in total bottom cover, northward extent, and density of *Syringodium*. *Syringodium* was not reported in the study area in 1961 and it had just begun to encroach upon and colonize the area near Three Islands in 1966 (to the east of the ICWW). *Syringodium* stands were not reported for the area west of the ICWW prior to 1977. Observations made in the spring of 1977 documented that *Syringodium* is now a co-dominant species with *Halodule* east of the ICWW and has begun to colonize some areas west of the ICWW. Since 1961 *Syringodium* has not only encroached upon areas east of the ICWW that were covered primarily by *Halodule* (some *Ruppia* was reported to the east of the ICWW usually near spoil mounds), but has locally replaced it as the dominant or "singular" species. *Syringodium* increased its northward extent between 1961 and 1977. Singleton (1974) and Breuer (1962) both reported that *Syringodium* had advanced as far as the northern parts of Port Isabel Bay by 1962, and McMahan (1965, 1966) stated that localized *Syringodium* stands had begun to colonize areas in the Three Islands vicinity by 1966. By 1977 *Syringodium* had extended its range to cover most of the deeper waters of the study area as far north as Mullett Island (within 5-6 miles of Port

Mansfield) and the southern limit of Redfish Bay. Previous mapping does not show *Syringodium* as far north as the southern part of Redfish Bay.

3. Decrease in distribution, occurrence and density of *Ruppia*. The 1977 mapping displays only two sitings of *Ruppia*--both east of the ICWW. The 1961 mapping included numerous stands of *Ruppia* both east and west of the ICWW, particularly in the area of spoil mounds. The trend apparently started as early as 1965 when McMahan (1965) reported that stands of *Ruppia* along the ICWW in Lower Laguna Madre had decreased in number and size since 1961. *Ruppia* had not been reported to have occurred as far east of the ICWW as 1977 fieldwork revealed. It might be assumed therefore that although *Ruppia* stands have decreased (and in places completely died out) in the study area, they have also changed in regard to their geographic extent in the lagoon.
4. No conclusive evidence for any changes in distribution and density of *Halophila* since Parks and Wildlife Department did not record its occurrence at any time in their mapping program.

Several factors are responsible for limiting seagrasses to specific areas in generally (relatively) shallow water. Phillips (1960) and Sculthorpe (1967) suggest that temperature is a primary factor. McMillan and Moseley (1967), and Hammer (1968) discuss the importance of hypersalinity tolerance as a limiting factor. Other limiting factors that must be considered are (from Kinne (1967)): sediment (substrate) type, turbidity, light extinction properties of water, water depth, current regime (including hydrography of area and tidal effect--both astronomical and wind-tidal), nutrient levels of the ecosystem involved, and dissolved gases. All are of physico-ecological importance in the distribution and density of seagrasses.

Hedgpeth (1967), in regard to Laguna Madre, stated:

> "The most obvious thing about ecosystem data collected in Laguna Madre is that the values of the various variables rise and fall with the progressions of the seasons. Therefore, it cannot be stated whether temperature or salinity per se have any control over the system; indications are that the systems are not directly dependent upon temperature and that they also seem independent of salinity."

Hedgpeth further goes on to quote Carpelan (1964) as stating that organisms in a natural salinity gradient may distribute themselves according to salinity optima and further, salinity per se is _not_ the only, or even the principal controlling factor in many distributions in nature. Hedgpeth and Carpelan are both most likely right, but their statements are deceiving as to the importance of temperature and salinity as limiting/controlling factors.

Kinne (1967) studied the relationship of marine organisms to temperature and salinity and made several key observations more applicable to this study than Hedgpeth's. They are as follow:

1. The number of different life forms, or species, per space unit is usually much smaller in estuaries than in the neighboring marine or fresh-water habitats. However, the number of individuals may be quite large especially if the estuary is eutrophic. Consequently,

intraspecific competition is frequently more pronounced than interspecific competition.

2. A single environmental factor does not normally govern the physiological responses and population dynamics in an estuary, but a combination of numerous factors counteracting, supporting, and modifying each other's physiological effects.
3. Significant changes in the ionic composition of the surrounding water may modify lethal limits and salinity preferences as well as capacities for growth, reproduction, and competition and, hence, may affect the abundance and distributional range of estuarine species.
4. Compensatory means for adverse salinity conditions are more immediately available and better developed than those for temperature. Adverse temperatures are tolerated rather than compensated for (as with salinity) and thus greatly affect activity, metabolic rate, reproduction, and other functions as well as structural aspects. Kinne (1967) worked mainly with marine invertebrates but applied many of his conclusions to estuarine vegetation thereby making his observations relevant to this study.

By knowing the primary limiting factors on seagrass distribution and density, one may speculate (in the absence of factual proof) as to why the seagrasses have extended their range northward through Lower Laguna Madre since 1961. Breuer (1962), McMahan (1966) and McGowen (1977) all cite the importance of the man-made engineering changes/ modifications to the Lower Laguna Madre system since 1948. Before construction of the ICWW in 1948, salinities in Lower Laguna Madre commonly averaged 60-70^o/oo (McMahan, 1966). Hypersalinity has been discussed previously as a controlling factor on seagrass distribution and density. Completion of the canal in 1949 helped alleviate hypersalinity in the Lower Laguna Madre. In 1958 Port Mansfield Pass was dredged through Padre Island connecting Redfish Bay with the Gulf of Mexico. Previously, the only water exchange with the Gulf in Lower Laguna Madre was through Brazos Santiago Pass (and through intermittent/ephemeral storm surge channels). Since stabilization of Mansfield Pass in 1962 salinity in Lower Laguna Madre (bay proper) has not exceeded 55^o/oo (McMahan, 1966). Moreover, Falcon Dam was emplaced on the Rio Grande River in 1953 and has served to effectively cut off any significant fresh-water discharge into the lagoon, thereby promoting a more stable salinity. Hence, since 1962 with the completion of the aforementioned man-made modifications, salinity has stabilized in Lower Laguna Madre through increased circulation and exchange of water. McMahan (1966) stated, "It is conceivable that all of these engineering feats helped to change the Lower Laguna Madre from a hypersaline environment sporadically influenced by extremes of high and low salinities to a more stable and less saline environment."

However, if one follows Kinne's (1967) conclusions on estuarine interactions to physical factors, then, stabilization of salinity alone cannot stand as having promoted the northward expansion of the seagrasses. Rather there must have been a combination of factors interacting to facilitate rapid expansion, colonization, and subsequent increases in density of the seagrasses through time. Other physical processes have been relatively stable, as with salinity, for the period

1961 to 1977. The only major climatic event in the area was Hurricane Beulah in 1967, but its effect was short term for the most part as concerns the physical environment. Temperature, rainfall, substrate type, and other factors limiting seagrasses are assumed to have been relatively "stable" (that is, not dramatically different on a yearly average) during interim years. Subsurface fieldwork during the summer of 1977 (plus that of H. N. Fisk's 1949 study) showed several interesting aspects of the depositional history of the study area and its relation to present trends and distributions.

1. Coring in the lagoon revealed that the top 1-1.25 feet of bay bottom adjacent to the General Land Office-NOAA tide gages accumulated in a submarine grassflat environment and not on a wind-tidal flat.
2. Fisk's study established through precise and exacting measurements that the delta plain underlying the wind-tidal flats/lagoonal bottom is subsiding at a rate of 0.33 inches per year. If one uses this figure and determines the amount of subsidence since 1948 for an emergent wind-tidal flat as decpited in Fisk's (1959) map a figure of approximately 9.5 inches is arrived at, in many places (especially near the Green Island area of the study area) this is about the depth of water over the lagoon bottom if one assumes, as maps show, that the wind-tidal flats extended almost to the ICWW in the late 1950's. (Note: vintage of Fisk's map is not known).

Subsidence of the lagoon bottom through historic time, year by year, has increased: (1) the areal size of the lagoonal bottom and its covering waters and consequently decreased the size of the wind-tidal flats; (2) the depth of water over the lagoonal bottom assuming no significant increase in water level of sedimentation rate through the lagoon. In addition to the increased size of the lagoon, wind tides (the primary force able to raise water level and control inundation of lowlands as astronomical tides are small and water level is assumed to be fairly constant for the lower lagoon) are resultingly able to inundate formerly emergent areas more frequently while other areas become constantly submerged through continued subsidence. The increase in bay bottom through subsidence of the underlying deposits in addition to the effect of wind tides, stabilized salinity, and improved circulation, and relatively "stable" physical factors have promoted and facilitated northward expansion of seagrasses through the Lower Laguna Madre.

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SELECTED REFERENCES

Breuer, J. P., 1957, Ecological survey of Baffin and Alazan Bays, Texas: Univ. Texas, Austin, Pub. of Inst. Marine Science, v. 4., no. 2, p. 134-155.

________ 1961, Biological survey of waters of the Laguna Madre of Cameron and Willacy counties and adjacent waters: Texas Parks and Wildlife Dept., Coastal Fisheries Job Completion Rept. M-9-R-3, Job No. E-4, 2 p.

Brown, L. F., Jr., Brewton, J. L., Evans, T. J., McGowen, J. H., Groat, C. G., and Fisher, W. L., in preparation, Environmental geologic atlas of the Texas coastal zone--Brownsville-Harlingen area: Univ. Texas, Austin, Bur. Econ. Geology.

Carpelan, L. H., 1964, Effects of salinity on algal distribution: Ecology, v. 45, no. 1, p. 70-77.

Carr, J. T., Jr., 1967, The climate and physiography of Texas: Texas Water Devel. Board Rept. 53, 35 p.

Collier, A., and Hedgpeth, J. W., 1950, An introduction to the hydrography of tidal waters of Texas: Univ. Texas, Austin, Pub. of Inst. Marine Science, v. 1, no. 2, p. 123-194.

Conover, J. T., 1958, Seasonal growth of benthic marine plants as related to environmental factors in an estuary: Univ. Texas, Austin, Pub. of Inst. Marine Science, v. 5, p. 97-147.

________ 1964, The ecology, seasonal periodicity, and distribution of benthic plants in some Texas lagoons: Bot. Mar., v. 7, p. 4-41.

Cornelius, S. E., 1975, Food choice of wintering Redhead ducks (*Aythya Americana*) and utilization of available resources in Lower Laguna Madre, Texas: Texas A&M Univ., M. S. thesis, 121 p.

Correll, D. S., and Correll, H. B., 1972, Aquatic and wetland plants of southwestern United States: U. S. Govt. Printing Office, Washington, D. C., 1777 p.

Edwards, P., 1976, Seaweeds and seagrasses in the vicinity of Port Aransas, Texas: Univ. Texas Press, Austin and London, 131 p.

Fisk, H. N., 1959, Padre Island and Laguna Madre Flats, coastal south Texas: Louisiana State Univ., 2nd Coastal Geog. Conf., p. 103-152.

Gunter, G., 1945, Some characteristics of ocean water and the Laguna Madre: Texas Game and Fish, v. 3, no. 11, p. 7, 19, 21-22.

Harry, H., 1976, Correlation of benthic mollusca with substrate composition in lower Galveston Bay, Texas: The Verliger, v. 19, no. 2, p. 135-152.

Hartog, C. den, 1970, The seagrasses of the world: North-Holland Publ. Co., Amsterdam, Holland, 275 p.

Hedgpeth, J. W., 1947, The Laguna Madre of Texas: Transactions, 12th North Amer. Wildlife Conf., p. 364-380.

________ 1967, Ecological aspects of the Laguna Madre, a hypersaline estuary, in Lauff, G. H., ed., Estuaries: Amer. Assoc. for Advancement of Science, Washington, D. C., p. 408-419.

Kinne, O., 1967, Physiology of estuarine organisms with special reference to salinity and temperature: general aspects, in Lauff, G. H., ed., Estuaries: Amer. Assoc. for Advancement of Science, Washington, D. C., p. 525-540.

McGowen, J. H., Garner, L. E., and Wilkinson, B. H., 1977, The Gulf shoreline of Texas: Processes, characteristics, and factors in use: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 77-3, 27 p.

McMahan, C. A., 1965, Survey, coastal waterfowl: Texas Parks and Wildlife Dept. Job Completion Rept. P-R Project W-29-R-18, Job 17, 8 p.

________ 1966, Survey, coastal waterfowl: Texas Parks and Wildlife Dept. Job Completion Rept. P-R Project W-29-R-19, Job 17, 25 p.

________ 1967, Survey, coastal waterfowl: Texas Parks and Wildlife Dept. Job Completion Rept. P-R Project W-29-R-20, Job 7, 9 p.

________ 1968, Biomass and salinity tolerance of shoalgrass and manateegrass in Lower Laguna Madre, Texas: Jour. Wildlife Management, v. 32, no. 3, p. 501-506.

________ 1969, The food habits of ducks wintering on Laguna Madre, Texas: New Mexico State Univ., M. S. thesis, 37 p.

McMillan, C., and Moseley, F. N., 1967, Salinity tolerances of five marine spermatophytes of Redfish Bay, Texas: Ecology, v. 48, p.

________, Lipkin, Y., and Bragg, L. H., 1975, The possible origin of peculiar *Thalassia Testudinum* reported from Texas as *Posidonia Oceanica*: Univ. Texas, Austin, Contributions in Marine Science, v. 19, p. 101-106.

Merkord, G., 1976, Texas A&I Univ., M. S. thesis, in preparation.

Odum, H. T., 1963, Productivity measurements in Texas turtlegrass beds and the effect of dredging an intracoastal canal: Univ. Texas, Austin, Pub. of Inst. Marine Science, v. 9, p. 48-58.

Odum, W. E., 1967, The influence of the seagrass community on the depositional environment of sediments: Rept. submitted to Organism-Sediment Interaction Seminar, sponsored by NSF, Bermuda Biological Station, 7 p.

Phillips, R. C., 1960, Observations on the ecology and distribution of the Florida seagrasses: Marine Lab. Florida, Prof. Papers Series, v. 2, p. 1-72.

________, McMillan, C., Battaker, H. F., and Heiser, R., 1974, *Halodule Wrightii* Ascherson in the Gulf of Mexico: Univ. Texas, Austin, Contributions in Marine Science, v. 18, p. 257-261.

Price, W. A., 1958, Sedimentology and Quaternary geomorphology of south Texas: Gulf Coast Assoc. Geol. Socs. Trans., v. 8, p. 41-75.

________, and Gunter, G., 1943, Certain recent geological and biological changes in south Texas, with consideration of probable causes: Texas Acad. Science Proc. and Trans., v. 26, p. 138-156.

Schubel, J. R., 1973, Some comments on seagrasses and sedimentary processes: Johns Hopkins Univ., Chesapeake Bay Institute, Ref. 73-12, Special rept. 33, 32 p.

Simmons, E. G., 1957, Ecological survey of the Upper Laguna Madre of Texas: Univ. Texas, Austin, Pub. of Inst. Marine Science, v. IV, no. 2, p. 156-200.

Singleton, J. R., 1964, Survey, coastal waterfowl: Texas Parks and Wildlife Dept. Job Completion Rept. P-R Project W-29-R-14, Job 17, 4 p.

Thornthwaite, C. W., 1948, An approach toward a rational classification of climate: Geog. Rev., v. 38, no. 1, p. 55-94.

West, R. L., 1969, Inventory of marine plants and animals important to waterfowl: Texas Parks and Wildlife Dept. Job Completion Rept. P-R Project W-29-R-21, Job 20, 12 p.

________ 1969, Inventory of marine plants and animals important to waterfowl: Texas Parks and Wildlife Dept. Job Completion Rept. P-R Project W-29-R-22, Job 20, 12 p.

________ 1971, Inventory of aquatic vegetation: Texas Parks and Wildlife Dept. Job Completion Rept. P-R Project W-29-R-23, Job 20, 9 p.

________ 1971, Inventory of aquatic vegetation: Texas Parks and Wildlife Dept. Job Completion Rept. P-R Project W-29-R-24, Job 20, 11 p.

________ 1972, Inventory of aquatic vegetation: Texas Parks and Wildlife Dept. Job Completion Rept. P-R Project W-29-R-25, Job 20, 7 p.

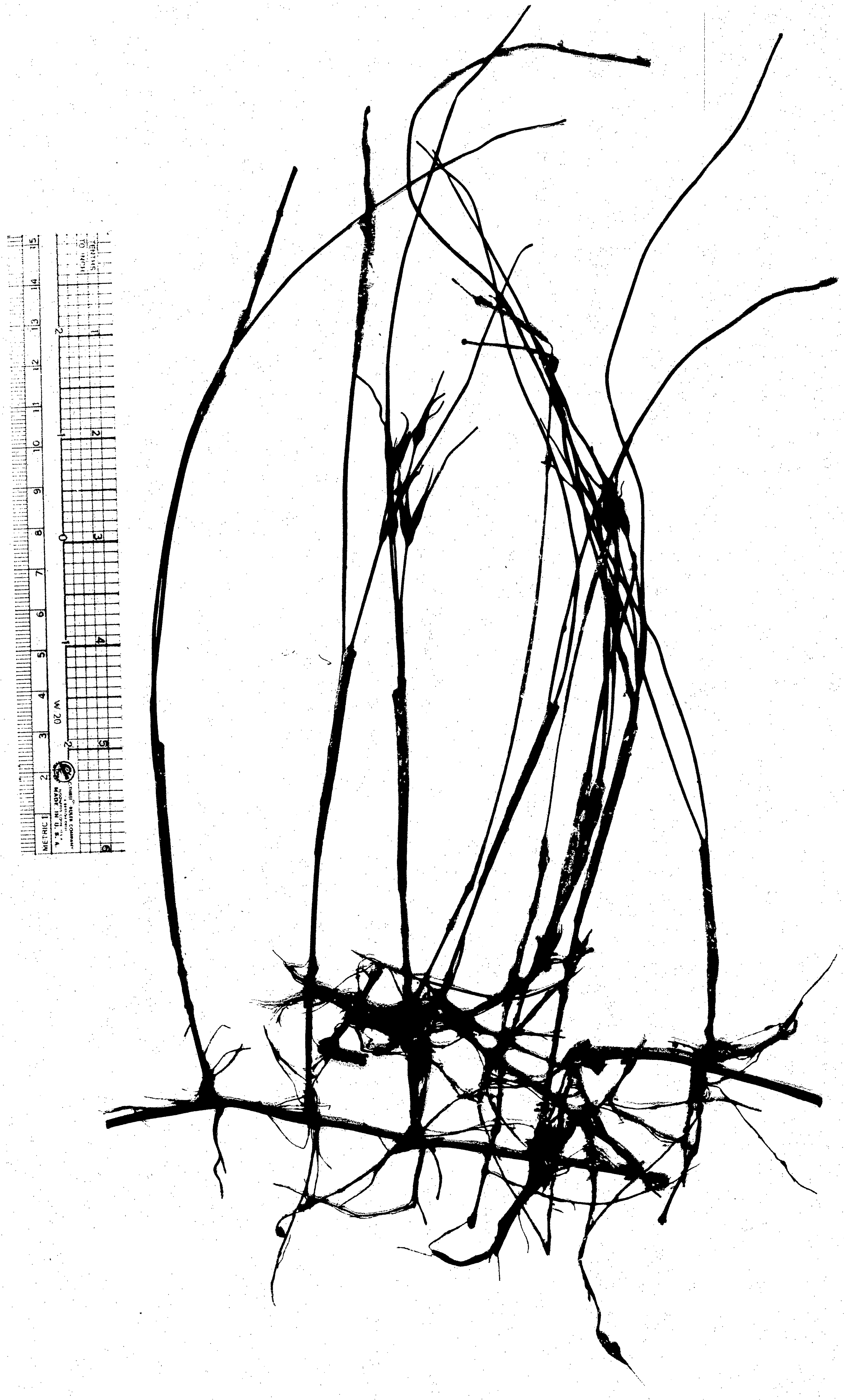
________ 1973, Inventory of aquatic vegetation: Texas Parks and Wildlife Dept. Job Completion Rept. P-R Project W-29-R-26, Job 20, 6 p.

APPENDIX

Seagrass illustrations taken from den Hartog (1970)

Algal information taken from Edwards (1976)

Figure 8. *Ruppia maritima* collected in Galveston Co.; from the Lundell Herbarium, Texas Research Foundation No. 2532.


TENTHS TO INCH
W 20
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MADE IN U.S.A.

Figure 9. *Ruppia maritima,* leaf-tip morphology; same specimen as figure 8, No. 2532.

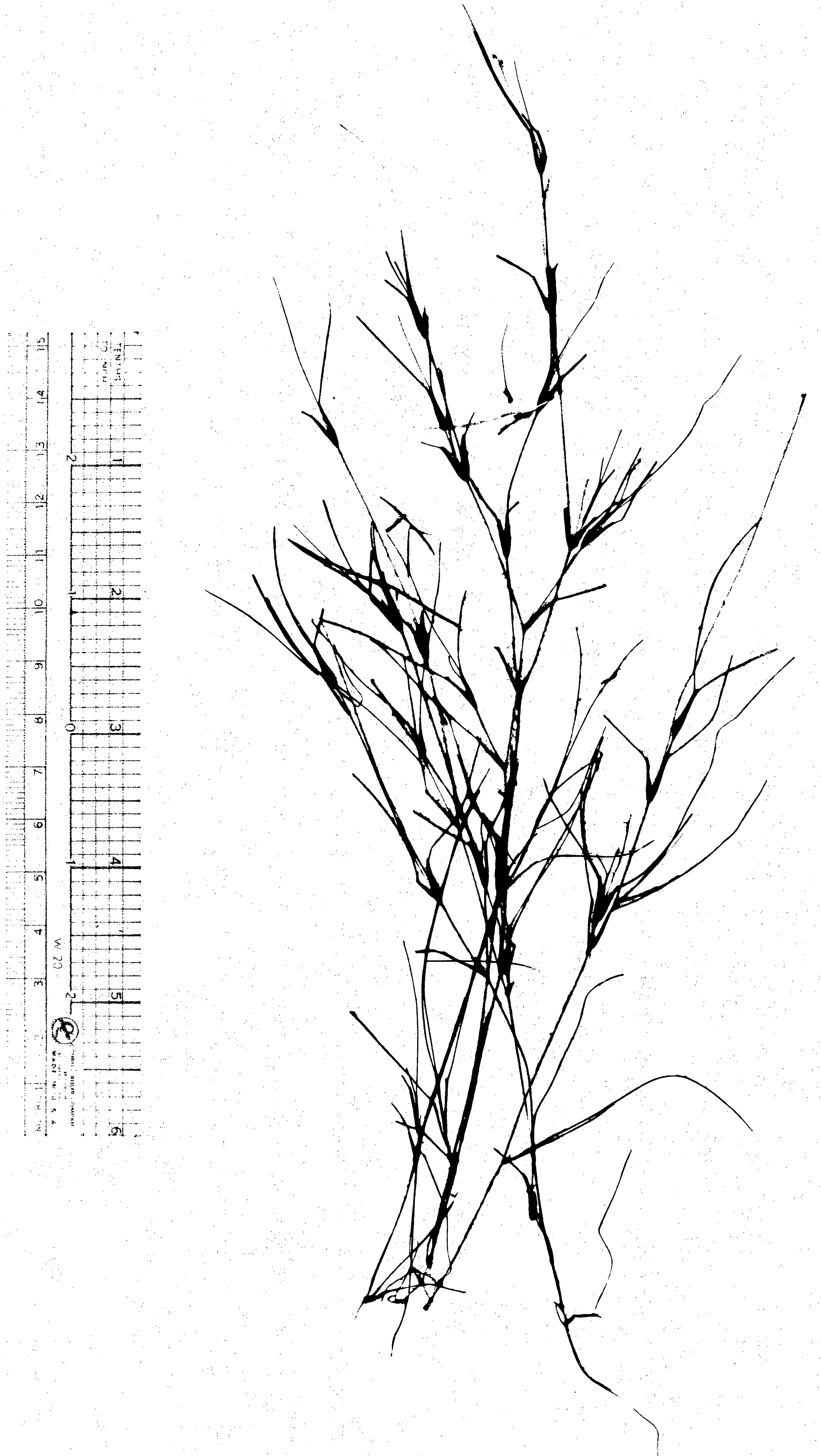

Figure 10. *Halodule wrightii* collected in Willacy Co.; from the Lundell Herbarium, Texas Research Foundation No. 1249.

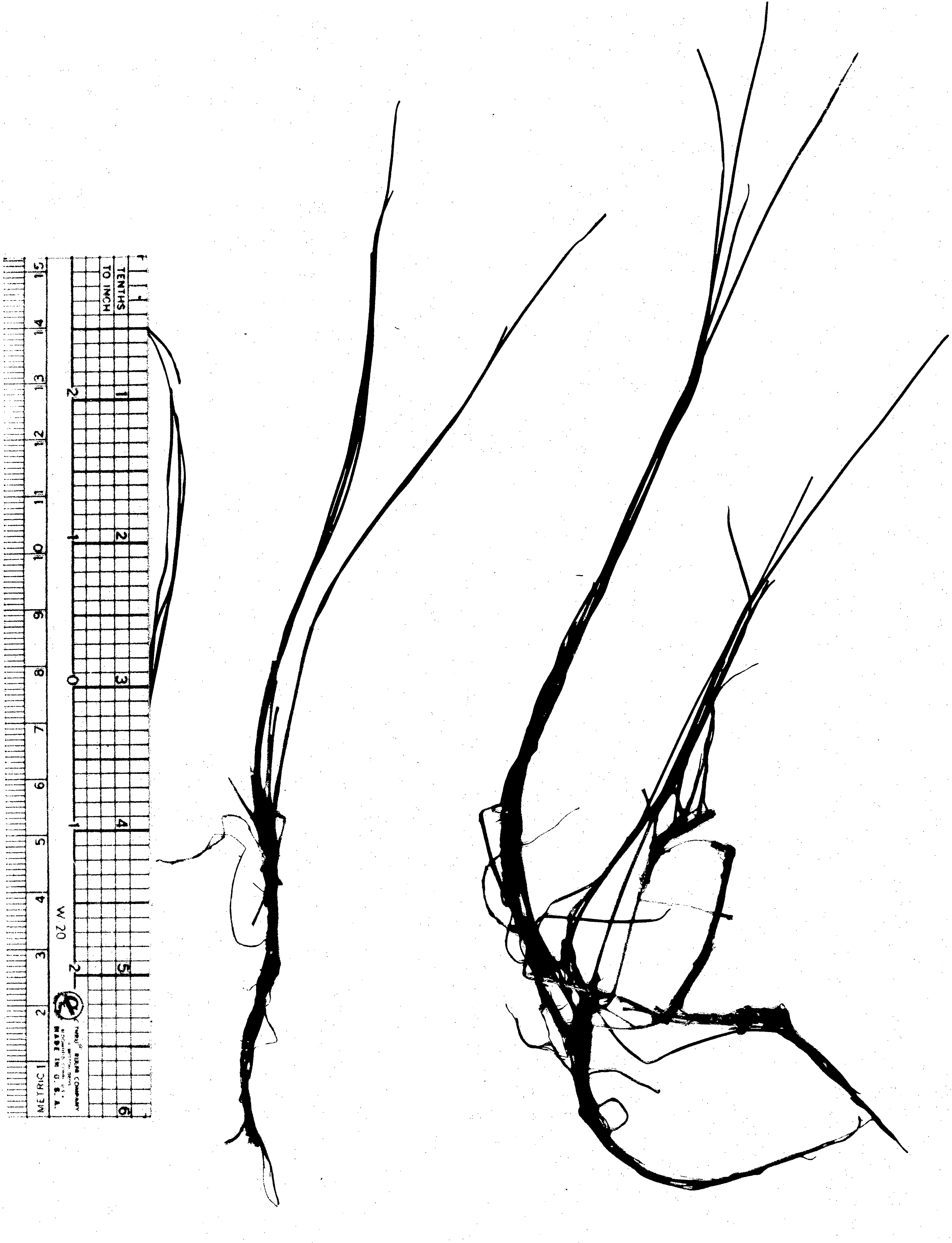
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Figure 11. *Halodule wrightii*, leaf-tip morphology; same specimen as figure 10, No. 1249.

Figure 12. *Halophila engelmannii* from Cameron Co.; from the Lundell Herbarium, Texas Research Foundation No. 25540.

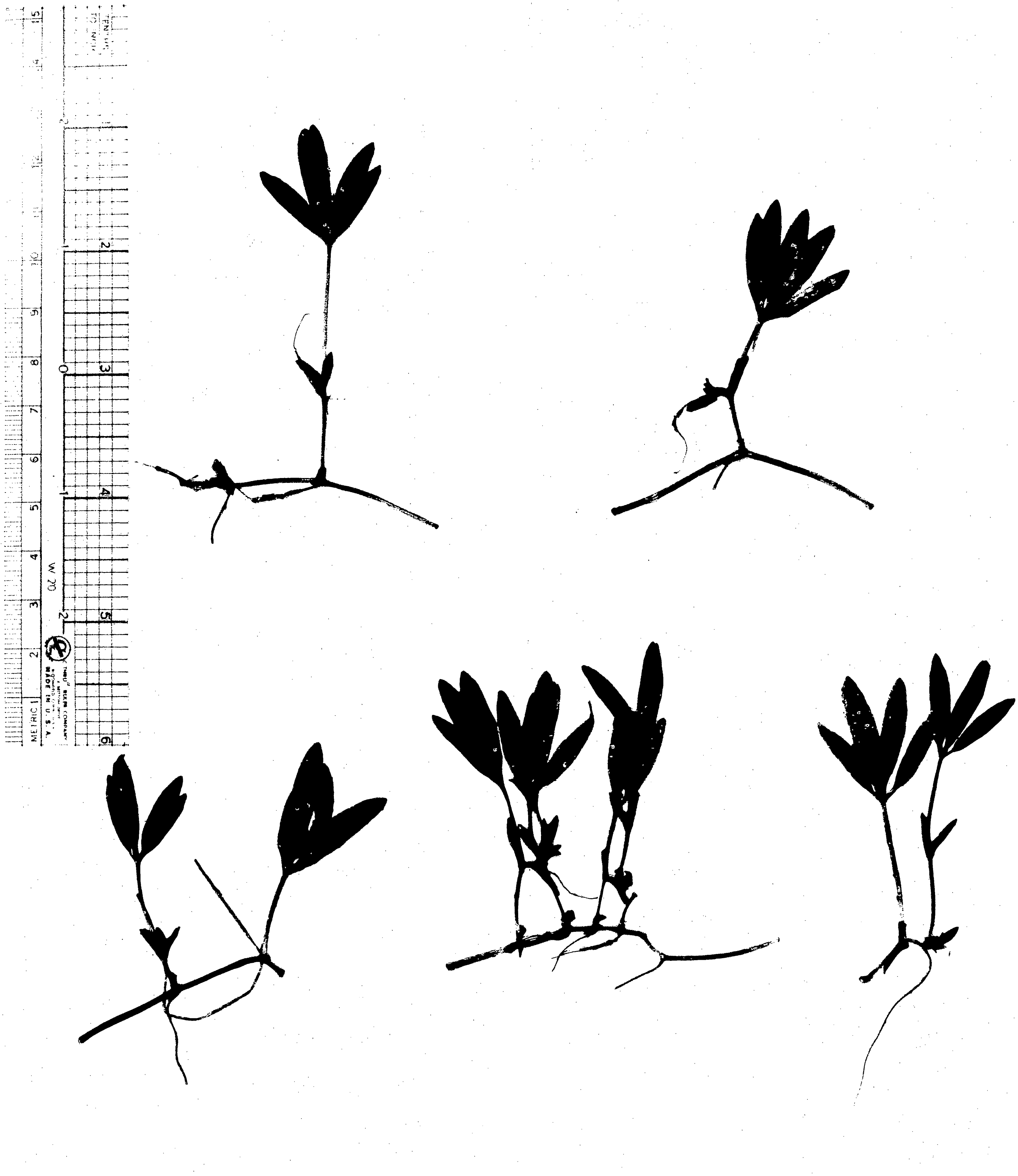
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Figure 13. *Thalassia testudinum* from Nueces Co.; from the Lundell Herbarium, Texas Research Foundation No. 31057.

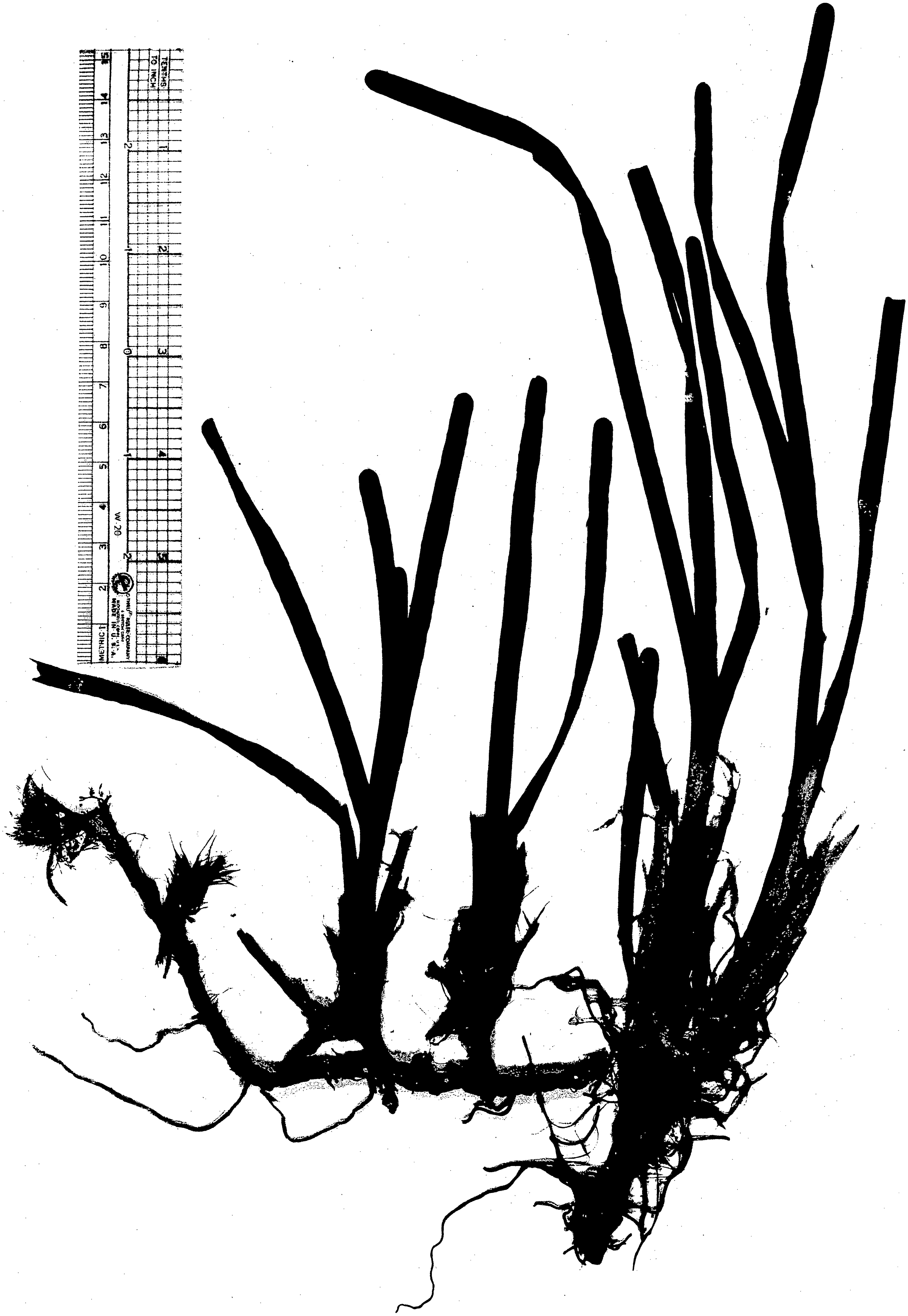
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Figure 14. *Syringodium filiforme* from Willacy Co.; from the Lundell Herbarium, Texas Research Foundation No. 1248.

Figure 8. *Ruppia maritima* collected in Galveston Co.; from the Lundell Herbarium, Texas Research Foundation No. 2532.

APPENDIX

Seagrass illustrations taken from den Hartog (1970)

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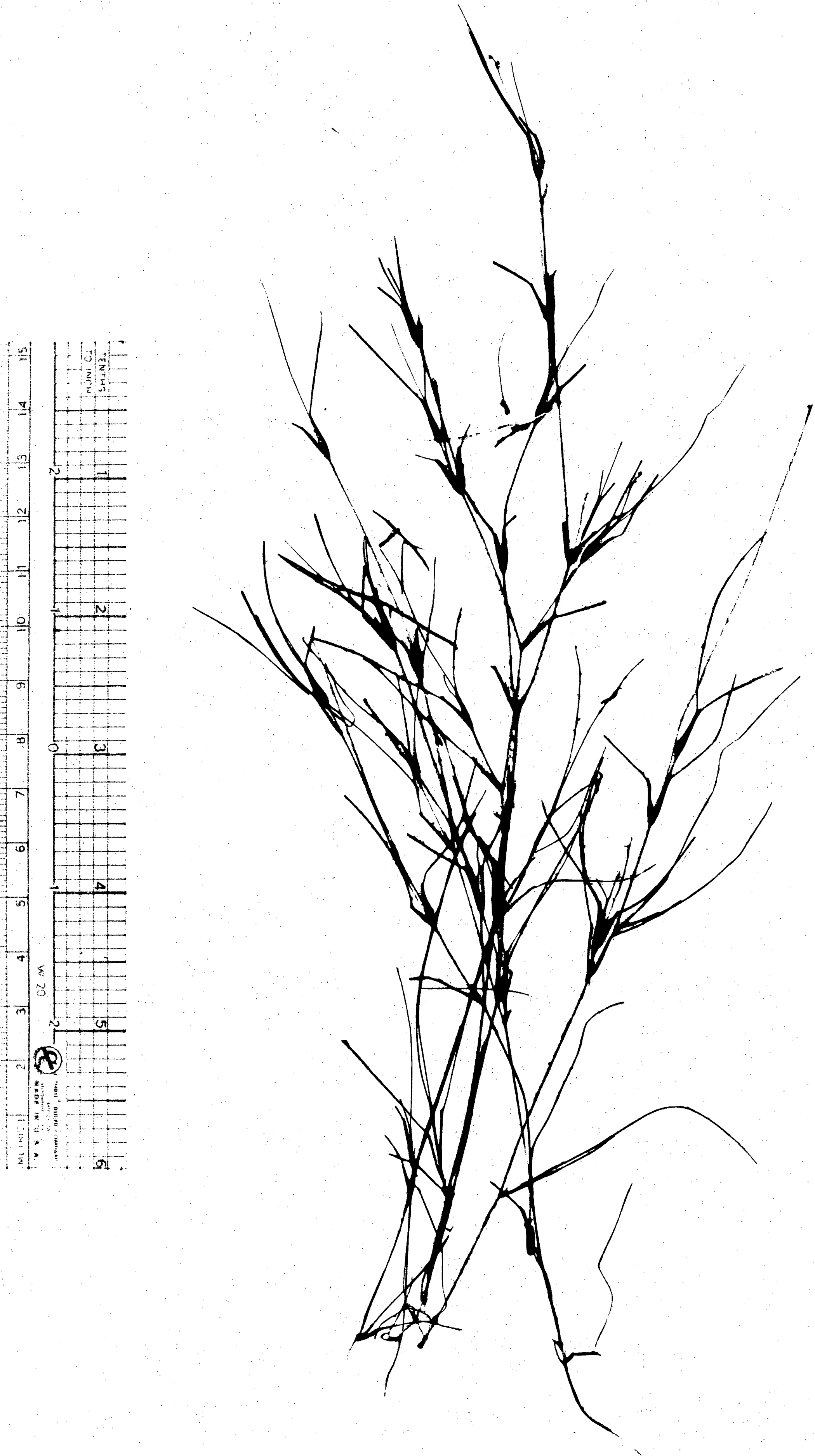

Figure 10. *Halodule wrightii* collected in Willacy Co.; from the Lundell Herbarium, Texas Research Foundation No. 1249.

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TENTHS TO INCH
METRIC 1
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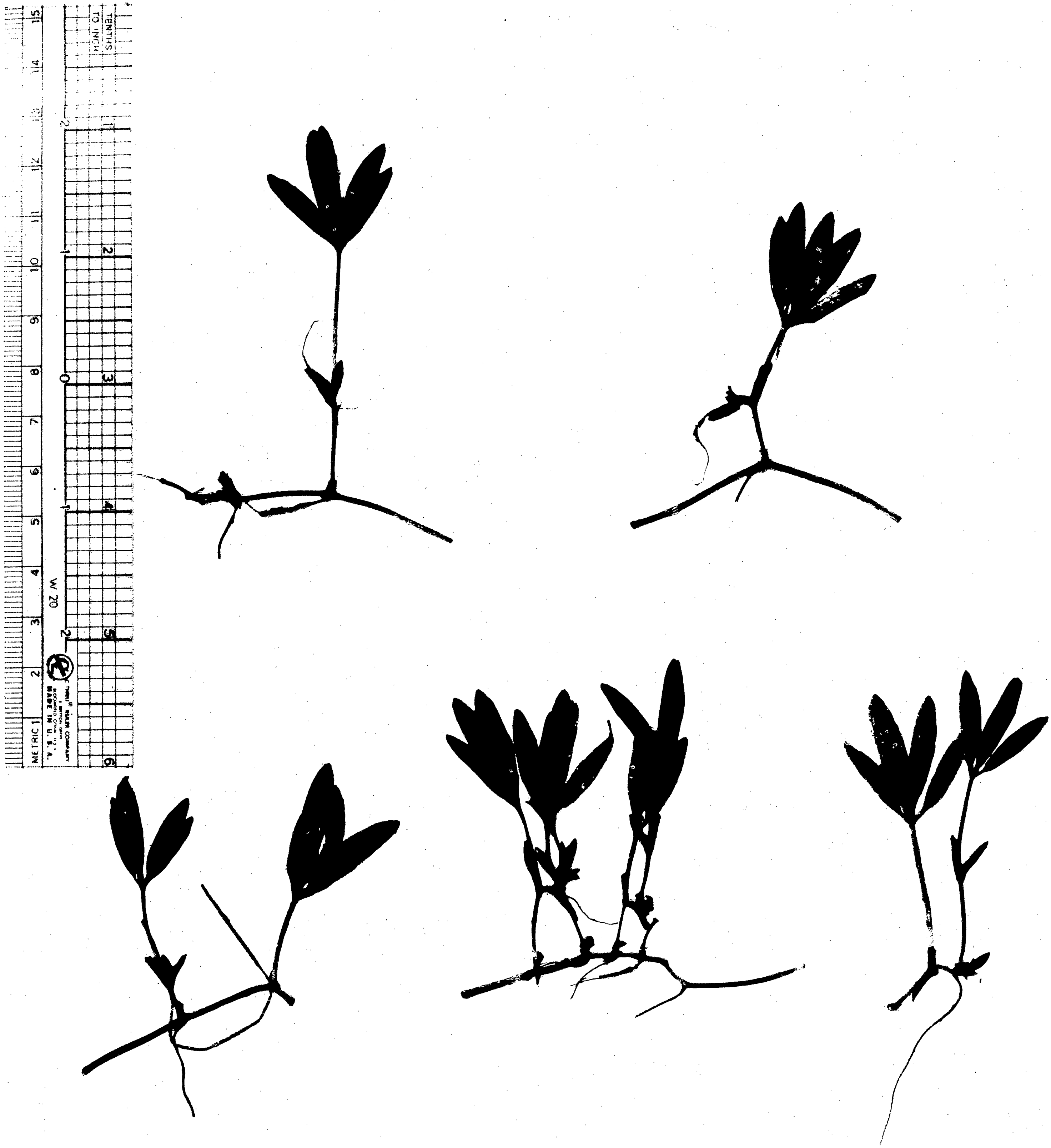
MADE IN U.S.A.

Figure 12. *Halophila engelmannii* from Cameron Co.; from the Lundell Herbarium, Texas Research Foundation No. 25540.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W 20
MADE IN U. S. A.

Figure 13. *Thalassia testudinum* from Nueces Co.; from the Lundell Herbarium, Texas Research Foundation No. 31057.

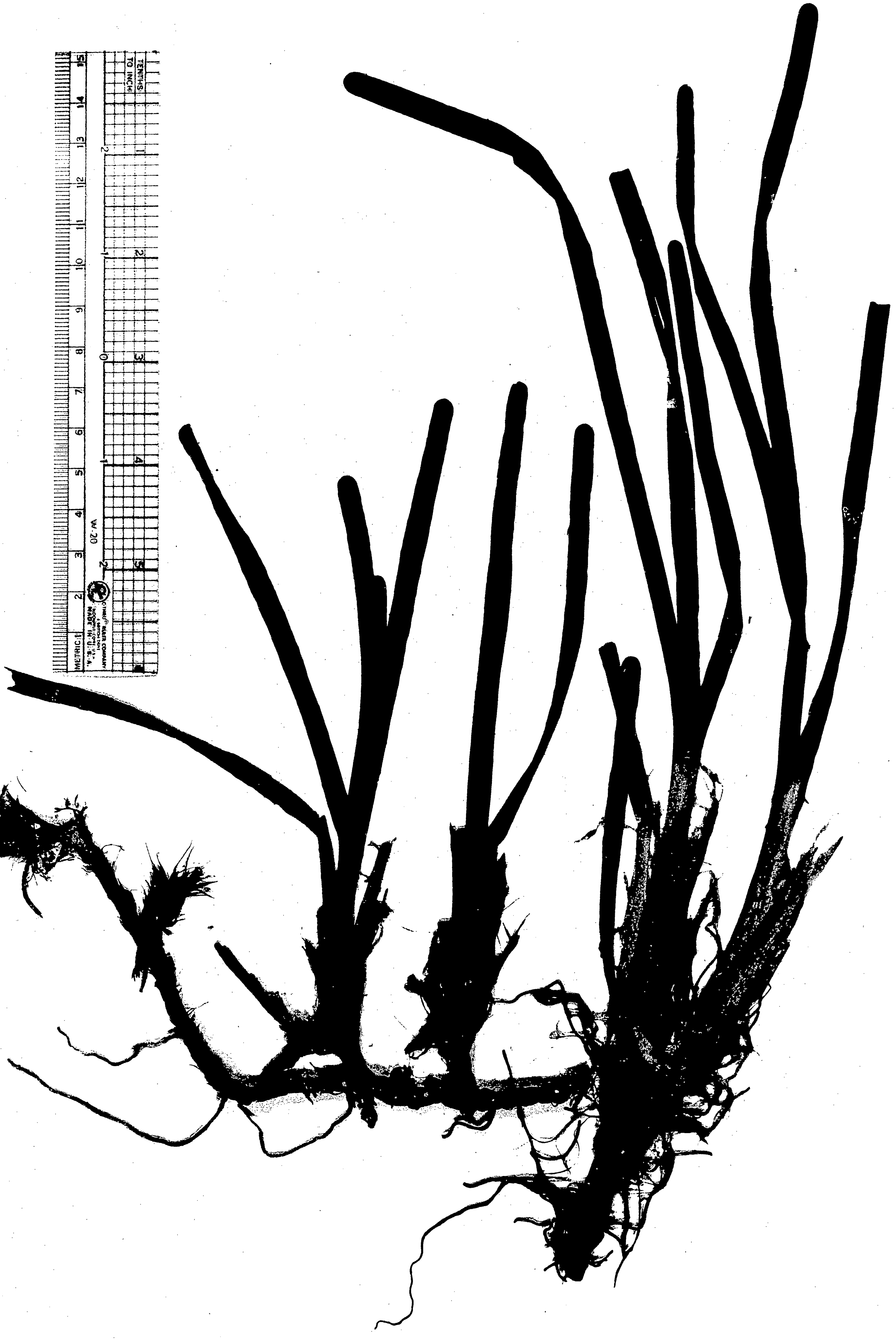
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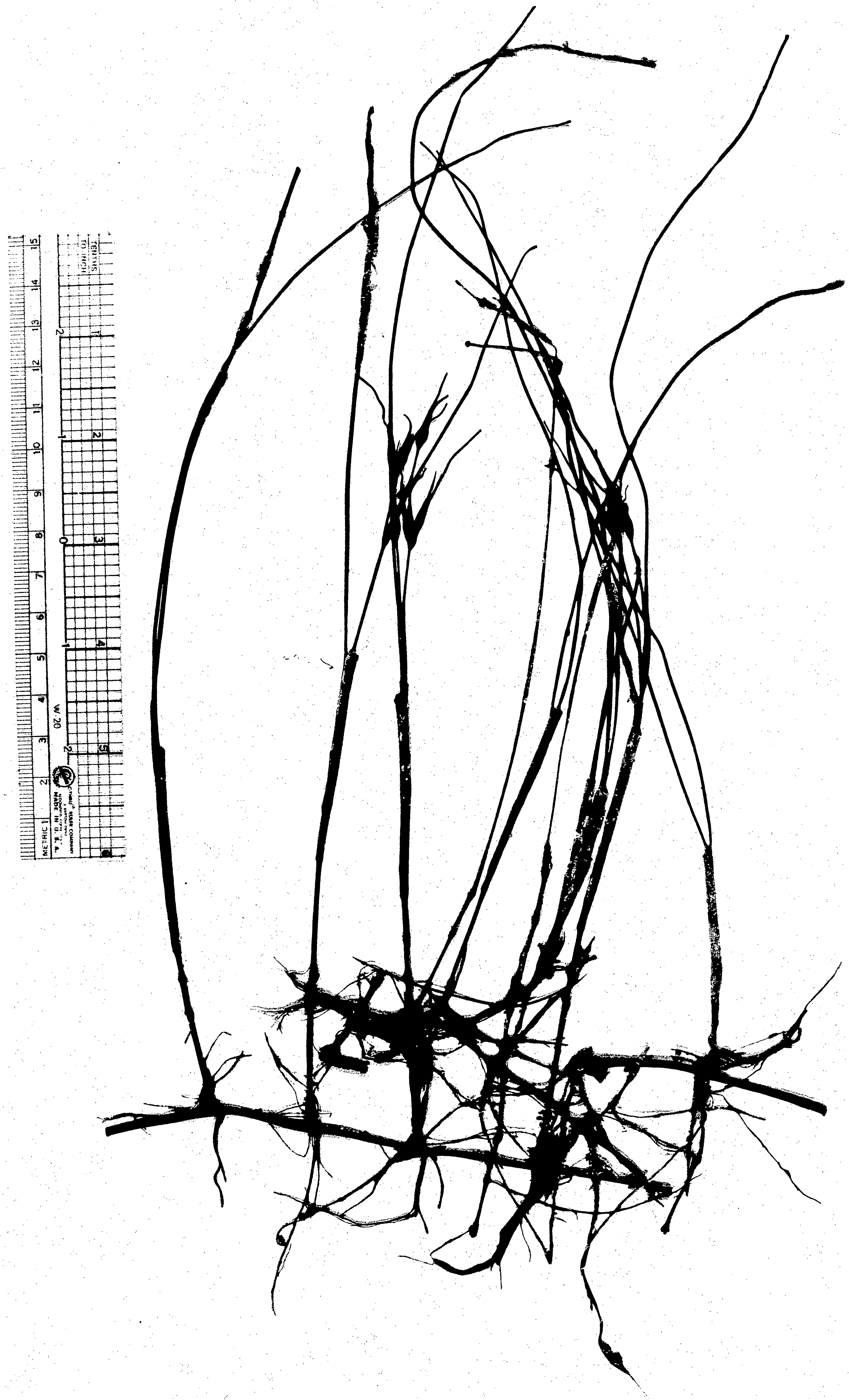
Figure 14. *Syringodium filiforme* from Willacy Co.; from the Lundell Herbarium, Texas Research Foundation No. 1248.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