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Centimeter-Level Orthometric Heights at Reference Points Along Florida's Big Bend Coastline from Global Positioning System (GPS) Static Surveys

by

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SUMMARY

Two static surveys using Global Positioning Systems (GPS) were performed along the Big Bend coastline of Florida to determine previously unknown orthometric heights of six benchmarks in tidal areas. The surveys were designed to tie these control points to tide gauges for use in marsh elevation surveys. Existing control from the National Geodetic Survey (NGS) was employed, and an accuracy of one part per million was the desired goal.

The St. Marks survey was performed over one day to collect information on the horizontal and vertical positions of two unknown sites on the Apalachee Bay south of Tallahassee. Four unknown sites along the coastline of Levy and Citrus counties were surveyed over four days to obtain similar information.

Post-processing the data followed using precise ephemerides, and network adjustments were performed to arrive at final results. One part per million (1ppm) precision, or a "B" order survey (FGCC, 1989), was achieved at one sigma, or one standard deviation, for both surveys.

PROJECT DESCRIPTION

Purpose

The U.S.G.S. Center for Coastal Geology's Florida Wetlands Project is a five-year geologic study of the Big Bend area of Florida's Gulf Coast. The wetlands along this coastline, from Apalachicola to Aripeka, are largely undisturbed, yet this region is experiencing rapid population growth which could affect this fragile environment. Some sections currently show signs of stress in wetland habitats, such as the decline of coastal hammocks and mangrove trees, possibly caused by changes in flooding, climate, and salinity levels. In these tidal wetlands, significant changes in habitat type and viability can result from changes in elevation as little as ten centimeters. Therefore, understanding changes requires accurate elevations particularly in context of sea level.

Vertical control was established in tidal areas to permit additional local surveys (including GPS kinematic surveys) and to determine the association of elevations with available tide gauges. These areas are sufficiently inaccessible making traditional survey techniques difficult. Global positioning system (GPS) static surveys were selected to provide the necessary vertical control. Nearby tide gauges can be surveyed to the control to obtain

tidal information relative to a known datum. Temporary tide gauges exist near the St. Marks control point (S170), operated by the National Biological Service (NBS), and the Cedar Creek mark (C380) (Fig. 1). A permanent gauge is maintained by the National Oceanic and Atmospheric Administration (NOAA)/National Ocean Service (NOS) at Cedar Key, providing tidal records since 1938.

The desired precision for these surveys was 1ppm, i.e. one centimeter of error per ten kilometers, and the standard deviation error of all adjusted positions should not exceed two centimeters. The centimeter level accuracy achievable with a "B" order survey is the minimum appropriate to make evaluations of elevation and flooding in this environment. Furthermore, position errors close to and greater than ten centimeters, or the equivalent of a "1st" order survey, would be too large in this wetland environment.

Survey Areas

Two separate surveys were designed in order to establish orthometric heights referenced to the North American Vertical Datum of 1988 (NAVD88) for six tidal control points (Fig. 1). Both were performed during the week of March 14-18, 1994. The St. Marks survey was performed on March 14, 1994, and the Levy/Citrus survey, on March 15-17, 1994.

The first survey was located in southern Wakulla County, south of Tallahassee in the Florida Panhandle, and dubbed "St. Marks" after the National Wildlife Refuge and river within the survey area. This area extended from the towns of Panacea in the southwest to Newport in the northeast, and Wakulla and the Gulf of Mexico as the northern and southern boundaries. Six existing control stations were used to determine the elevation of two unknown sites -- one at Wakulla Beach (S160) and the other located near the mouth of the St. Marks River (S170). The Wakulla Beach station was located near the site of a study on salt barren habitats (Hoffman 1992). The St. Marks station lies in the St. Marks National Wildlife Refuge (NWR) and is central to NBS and Fish and Wildlife Service (FWS) studies. The survey area spans 25 kilometers East-West and 20 kilometers North-South with lines between stations no longer than twenty-one kilometers (Fig. 2). The second survey area extended from the town of Suwannee in Dixie county southward through Levy and Citrus counties to the town of Chassahowitzka. Thirteen control points were occupied to obtain elevations for four unknown positions: one near the Waccasassa River mouth in Levy county (L260), another on Turtle Creek (L270), also in Levy county, and two along the coastline of Citrus county, one near study sites of the University of Florida at Ozello (C370) and the other next to a tide gage (# 2856020824127) operated by the USGS Water Resources Division (WRD) as part of this study at Cedar Creek (C380). This area spans 75 kilometers East-West and 90 kilometers North-South with vectors up to 64 kilometers (Fig. 3). These sites are central to a series of studies being conducted within this Wetlands Project and also to complement research by the University of Florida.

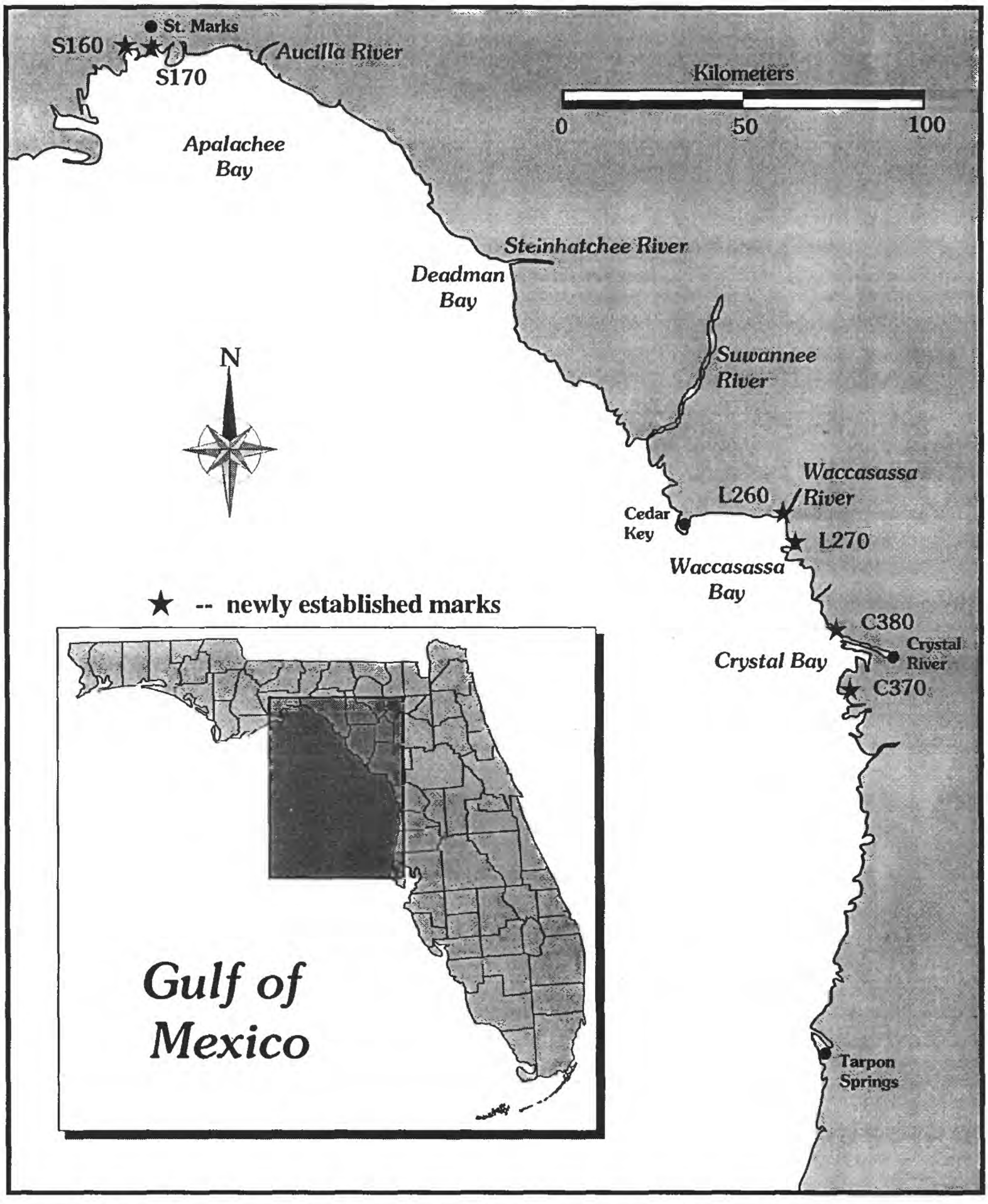


Fig. 1 . Study area along the Florida Big Bend Coast. Numbers indicate survey names.

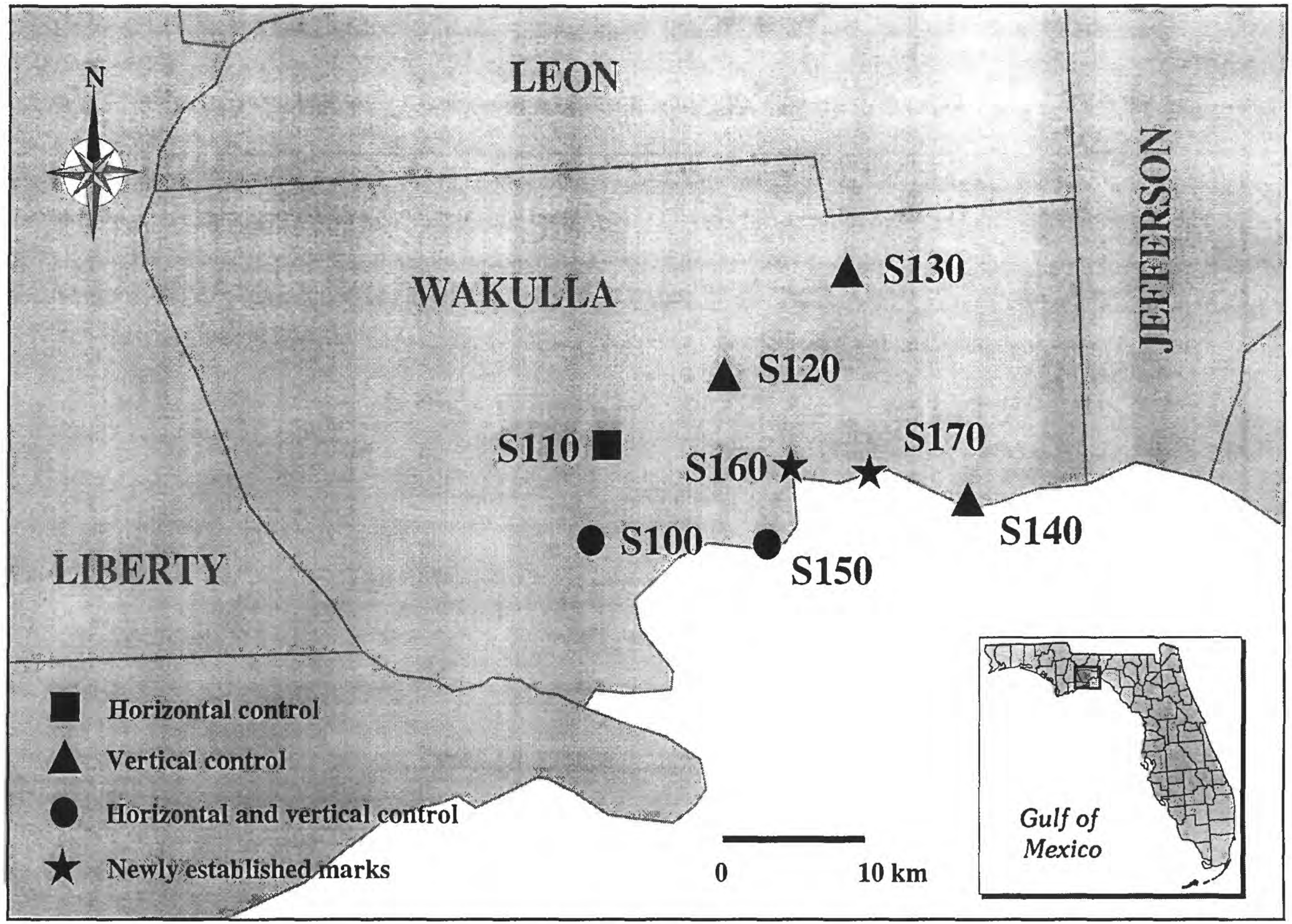


Fig. 2. St. Marks survey area with geodetic control and newly established marks.

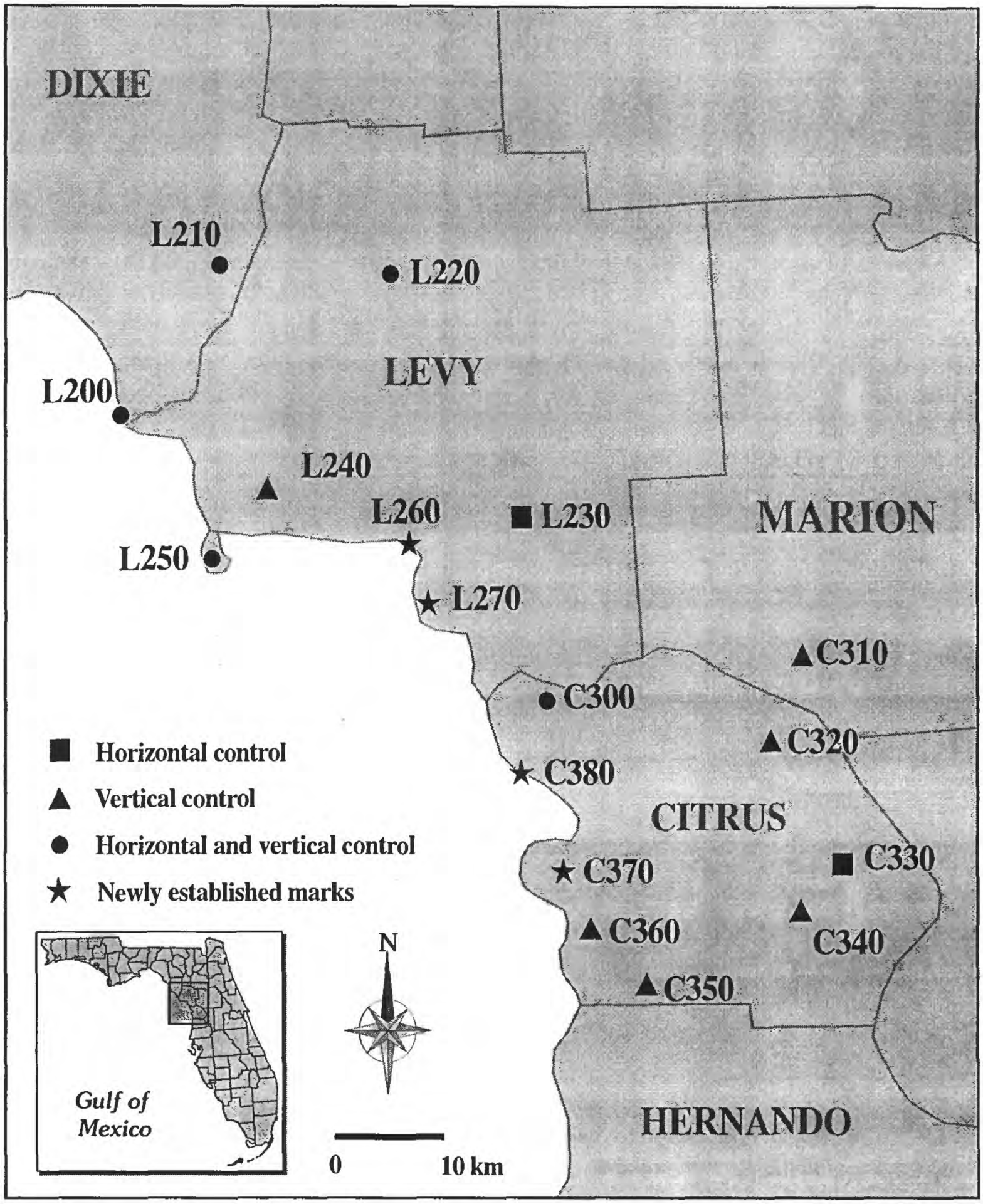


Fig. 3. Levy/Citrus survey area with geodetic control and newly established marks.

Equipment

Highly sophisticated GPS equipment was needed to achieve the accuracy desired. Four dual-frequency Ashtech receivers were used, two model P-12 and two model Z-12 (an upgrade from P-12). Each receiver was equipped with one megabyte of memory. Anti-spoofing (A/S) had been activated during the survey time frame which required putting the two P-12 receivers into "codeless" mode, while the Z-12 receivers automatically activated a tracking mode which mitigated the A/S effects. Two GPS fixed-height tripods were used, along with two conventional fiberglass tripods with adjustable legs. Optical plummets for the adjustable tripods facilitated centering and leveling. Post-processing and network adjustments were conducted using Ashtech's GPPS and FILLNET software.

SURVEY PREPARATION

Evaluation of Available NGS Control

Horizontal and vertical geodetic control was obtained from NGS on a series of diskettes containing all control for each of the following counties: Wakulla, Dixie, Levy, Citrus, and Marion. Florida's High Accuracy Reference Network (HARN) establishing horizontal coordinates by GPS observations has been completed, which made possible the use of high accuracy horizontal control referenced to the North American Datum of 1983 (NAD83) for both surveys. High accuracy vertical control as part of the HARN was not available. Existing vertical control in both surveys was leveled with traditional survey techniques and have been adjusted by NGS (with VERTCON, vertical conversion software) to NAVD88 heights from the National Geodetic Vertical Datum of 1929 (NGVD29).

Order "B" horizontal and "1st" order vertical were the most accurate control available in each survey area. A minimum of two "B" order horizontal stations and three "1st" order vertical benchmarks were secured in three areas: Wakulla, Levy, and Citrus counties. Levy and Citrus counties together covered a large area but were treated as one survey, connected by two known sites to strengthen the overall network. Most of the vertical control within seven kilometers of the coastline in Citrus county were posted benchmarks. Three posted marks were occupied with a code of "A", indicating a distribution rate of 0.0 through 1.0 millimeters per kilometer. They are designated "posted" since the data for these marks were published after the initial NAVD88 height publication. The distribution rate was applied to the original leveling data to indicate the usefulness of the posted marks. The posted "A" designation was considered to be compatible with the survey goals, and the proximity of these marks to the tidal marsh was essential to a well-balanced network.

Reconnaissance of Control

Potential points were selected for recovery once they had been prioritized according to order of accuracy, last documented recovery, and accessibility. Reconnaissance was necessary for the physical inspection of each station to determine if they were recoverable and suitable

for GPS surveys. Most benchmarks were challenging to find and problematic to use as they were under tree canopy or ran alongside old railroad beds and roads where power lines, and therefore, multipath interference was prevalent. Order "B" horizontal stations were usually not difficult to locate from their recent installments between 1988 and 1990 at local airports or adjacent to major highways, and multipath was generally not a problem at these sites. Only forty percent of all the control stations pursued was actually recovered, and of these, half were in good condition and suitable for GPS occupation. Many marks were not found due to ambiguous site descriptions, urban development, road regrading, railroad track removal or vegetation growth. A hand-held GPS unit proved helpful in locating benchmarks. Location descriptions, special requirements for GPS use, access needs, the station names, and NGS permanent identifier (PID) numbers were recorded on a site recovery form to maintain records of useable control. Photographs were also taken of each control point recovered and obstruction diagrams were prepared for use in mission planning using a Brunton compass.

Relocated Benchmarks

Needed vertical control which did not meet optimal conditions were relocated to temporary points. Three benchmarks were moved due to their tree canopy obstructions: 872 8130 TIDAL 3 (S140) at the St. Marks lighthouse in the National Wildlife Refuge; Dunnary RM3 (L200) at the town of Suwannee in Dixie county; and 872 7274 TIDAL 4 (C360) at Mason Creek near Homosassa in Citrus county. This was accomplished by using a laser level to relocate the mark to a masonry nail installed in the cement nearby or to an installed monument. New leveling measurements--closure error and new orthometric height--were recorded at the relocated site and are listed in Table 1. The laser surveys were closed within one millimeter.

Monumentation

Two of the unknown benchmarks occupied existing control stations: 9.332 at Ozello (C370) and Waccasassa Azimuth 1934 (L260). Benchmark C370 was designated as a posted vertical with a code of "NC" for a "No-check spur" meaning the accuracy of this point was not computed. The accuracy of benchmark L260 was also unknown. However, due to their prime locations near the coastline, both were chosen as unknowns for the Levy/Citrus survey.

Installation of five additional monuments was necessary due to the unsuitability of a present mark or the lack of any in the vicinity. For approximate heights from monuments to marsh surface, see "Recovering Newly Established Benchmarks" starting on page 16.

At Cedar Creek/CCMP (C380), the depth to bedrock was determined with a probe and a hole was dug using a post hole digger until the soil collapsed upon itself. A three inch aluminum casing was then inserted into the hole, driven to refusal at the limestone surface at approximately two meters, and cleaned out. The casing was filled with cement which was tamped down to reduce and remove any air pockets. A mark was made in the top of the casing. Using a laser level, the monument was surveyed into the WRD tide gage and WRD control mark (RM1) located near C380. See p. 20 for measurements associated with these marks. The Cedar Creek benchmark was installed in a patch of *Distichlis spicata*.

Table 1. List of control with order of accuracy, published (if known) latitude, longitude, and orthometric heights with relocation/installment agency, closure error, and new orthometric heights upon releveling.

Site	Published Designation	Horizontal (H) and/or Vertical (V) Order		Published Latitude (N)	Published Longitude (W)	Published Orthometric Height (NAVD88)	Relocated or Installed	Closure Error/New Height (NAVD88)
S100	Panacea Reset	1H	2V**	30° 04' 04.11200"	084° 23' 20.22162"	10.550m		
S110	FLGPS 14	BH**	--	30° 06' 21.75553"	084° 22' 46.43347"	n/a		
S120	165 CMP USGS	--	1V	30° 08' 37"	084° 18' 05"	3.918m		
S130	G 283	--	1V**	30° 11' 49"	084° 13' 02"	3.847m		
S140	872 8130 TIDAL 3	--	1V**	30° 04' 25"	084° 10' 45"	1.962m	Relocated to nail by USGS	+/- 0.0006m 1.900m
S150	Shell Point 2	BH**	1V**	30° 03' 27.78482"	084° 17' 20.49409"	2.104m		
S160	Wakulla Beach*	n/a	n/a	n/a	n/a	n/a	Installed by USGS	n/a
S170	S.E.T. 4*	n/a	n/a	n/a	n/a	n/a	Installed by NBS	n/a
L200	Dunnary RM3	1H	2V	29° 19' 35.73673"	083° 09' 09.32542"	1.305m	Relocated to nail by USGS	+/- 0.0006m 1.279m
L210	Keen	1H	2V**	29° 25' 39.15126"	083° 02' 16.61863"	4.590m		
L220	Barrow 2	BH**	1V**	29° 28' 29.04147"	082° 49' 43.77412"	12.895m		
L230	FLGPS 35	BH**	--	29° 09' 51.31877"	082° 38' 24.33711"	n/a		
L240	Lukens AZ Reset 1960	--	1V	29° 11' 23"	083° 00' 25"	2.951m		
L250	Tank RM3	1H	1V**	29° 08' 20.73149"	083° 02' 18.96653"	6.762m		
L260	Wacca Azimuth 1934	Unk.	Unk.	Unk.	Unk.	Unk.		

L270	Turtle Creek*	n/a	n/a	n/a	n/a	n/a	Installed by USGS	n/a
C300	CR 10 FLDNR	BH**	aV	29° 00' 39.82183"	082° 39' 43.76384"	16.697m		
C310	Z 20	--	1V	29° 03' 10"	082° 23' 27"	19.408m		
C320	Z 265	--	1V**	28° 57' 16"	082° 24' 43"	25.985m		
C330	INVERPORT	BH**	--	28° 48' 38.64227"	082° 18' 59.30272"	n/a		
C340	N 265	--	1V**	28° 47' 28"	082° 23' 01"	23.050m		
C350	CR 39 FLDNR	--	aV	28° 42' 49"	082° 33' 09"	2.424m		
C360	872 7274 TIDAL 4	--	aV**	28° 45' 49"	082° 38' 01"	1.881	Relocated to Installment by USGS	0.0009m 0.371m
C370	9.332	--	NCV	28° 50' 13"	082° 38' 53"	2.601m		
C380	Cedar Creek/CCMP*	n/a	n/a	n/a	n/a	n/a	Installed by USGS	n/a

Note: * indicates an assigned name to new benchmarks
** indicates horizontal and/or vertical position held fixed in final constrained adjustment

The same monumentation procedures were followed at Mason Creek where the existing benchmark, 872 7274 TIDAL 4 (C360), was relocated to the installed monument in *Spartina alterniflora* marsh.

At St. Marks, the S.E.T. 4 (S170) was set by the NBS using similar techniques except a center rod was not used and the pipe casing does not have flat surface on top. This casing is used as the base for a table used in measuring relative millimeter changes in marsh elevations.

At Wakulla Beach (S160), a temporary monument was installed where the site was probed to bedrock, and a one inch galvanized steel pipe with cap was driven to refusal. The monument was installed in a cluster of *Salicornia virginica.*

A fifth mark, Turtle Creek (L270), was installed on the edge of an "island" (a hammock) near the mouth of Turtle Creek below the Waccasassa River by the University of Florida. The monument consists of concrete mold, set directly on the limestone.

Mission Planning

Geodetic control used in the survey was selected if it presented a clear view and was not in proximity to magnetic fields or other objects which might cause multipath interference. Most stations met these requirements. When sufficient control had been recovered to meet the specifications for the survey networks, a balanced distribution of points was selected and entered into Ashtech's Mission Planning software. St. Marks and Levy/Citrus files were created and information for each mark was entered into the project file: site name, latitude, longitude, orthometric height (if known), site description, and obstruction diagram. (See Table 1 for a complete list of all positions occupied in these surveys). Upon obtaining an almanac, it was possible to choose the most appropriate windows of time for observation based on the number of satellites available and the modeled Position Dilution of Precision (PDOP) values for each time frame. A minimum of four satellites with good geometry was needed for all sessions.

SURVEY PROCEDURES

Four two-person teams each with receivers and tripods travelled between selected sites, occupying each position during a specified time slot according to the mission plan. Survey protocol allowed for difficulties encountered in communication, transportation for each team, and travel time for teams accessing positions by boat. Time allotted included twenty to thirty minutes for set-up and take-down, forty-five to sixty minute site occupations with a recording interval of 10 seconds, and travel time according to distance and route complications. Working from sunrise to sunset allowed five to six sessions of data to be collected each day.

Network configuration and positions occupied in each session took into consideration physical proximity, occupation of redundant vectors and network completeness. Receivers were downloaded each evening, and preliminary post-processing was performed to ensure the collection of good data from the day's observations.

ANALYSIS AND RESULTS

Post-Processing

Precise ephemerides were downloaded from the U.S. Coast Guard Bulletin Board, run through utility software, and formatted for use in Ashtech's GPPS post-processing software with the ORBITS program to achieve more precise positions.

Different modes of post-processing were available and utilized. Dual frequency rapid static processing was performed for vectors established between two Z-12 receivers. Receiver combinations of Z-12 with codeless, and codeless with codeless receivers were processed either using the widelane, L1-frequency only, or the L1C method depending on the length of the vectors and the type of observables (codes) involved. If one method yielded a sub-standard solution, other methods were tried. Changing program parameters such as elevation angle, satellite vehicle omissions, or satellite reference vehicle was necessary at times to arrive at a good solution.

Once all vectors had been processed with adequate solutions, they were imported into the network adjustment software, FILLNET, for checks on internal survey accuracy and to assess the local control as well as how the network fit the local control. A free adjustment was performed to check for blunders, vectors which exceed modeled error estimates, and errors in vertical control. A comparison of the published orthometric heights and the free adjustment orthometric heights facilitated identification of questionable control. A final constrained adjustment was produced based on the published values of only the reliable local control.

Vectors which did not fit the desired error estimates from the free adjustment and loop closure analysis were eliminated. New vectors were reoccupied to replace vectors which were required for loop closures and sufficient vector redundancy Reoccupation on November 4, 1994, using Z-12 receivers produced vectors with acceptable solutions. A satisfactory free adjustment was obtained with new vectors, and new orthometric heights were secured from a final constrained adjustment (see Table 2). Table 3 lists the vectors included in the final adjustments. Diagrams of these vectors are shown in Figs. 4 and 5.

Results

The orthometric heights of the unknown sites were computed by importing the geoid separations of their positions from a geoid surface model, GEOID93 (software developed by NGS), into FILLNET. With their GPS-derived ellipsoid height from GPPS, the equation, EH = OH + GH was used--where EH is the ellipsoid height, OH is the orthometric height, and GH, the geoidal separation--to obtain the orthometric height or elevation. All elevations are given in meters and referenced to the NAVD88 datum. Latitude and longitude was referenced to the NAD83. The NGVD29 orthometric height was obtained by subtracting the VERTCON model value algebraically from the NAVD88 height (see Table 2). The GEOID93 model is considered accurate at one to two centimeters over ten kilometers, while the VERTCON 2.0 model (also developed by NGS) is considered accurate to two centimeters, both at the one sigma level.

A precision of 1ppm was achieved at the one sigma level, and standard deviation errors on all adjusted positions of the unknown sites were less than one centimeter in both surveys. To obtain accuracies at two sigma, roughly a 95 percent confidence level, the statistics are doubled which produces a survey accuracy of two centimeters at two parts per million.

These GPS surveys adequately provided the vertical accuracy needed for obtaining base positions for future kinematic surveys and tieing marsh elevations to water level records. Centimeter-level accuracy surveys will enable researchers to evaluate the relationship between changes in the marsh and sea level fluctuations.

Table 2. Final positions of new marks

Site	Survey Name (New or Published)	GPS-Derived Latitude and Longitude (NAD83)	GPS Derived Orthometric Height in meters (NAVD88)	NGVD29 Heights Based on VERTCON 2.0 in meters
S160	Wakulla Beach (New)	30° 06' 16.83912" N 084° 15' 44.24455" W	0.633m	0.833m
S170	S.E.T. 4 (New)	30° 06' 02.82236" N 084° 12' 41.06485" W	0.566m	0.767m
L260	Wacca Azimuth 1934 (Pub)	29° 09' 51.02205" N 082° 48' 31.42155" W	0.861m	1.101m
L270	Turtle Creek (New)	29° 06' 54.54502" N 082° 47' 06.76271" W	0.561m	0.819m
C370	9.332 (Pub)	28° 50' 13.87690" N 082° 38' 52.15640" W	2.643m	2.895m
C380	Cedar Creek/ CCMP (New)	28° 56' 03.04315" N 082° 41' 26.92819" W	0.714m	0.991m

Table 3. List of vectors included in final adjustments from both surveys followed by the number of reoccupations.

St. Marks (Total = 36 vectors)

S100-S110 (2)
S100-S170
S110-S120
S110-S140 (3)
S120-S140 (2)
S130-S110
S130-S120
S130-S140 (3)
S130-S160
S130-S170
S140-S100
S140-S160
S140-S170 (2)
S150-S100
S150-S110 (3)
S150-S120
S150-S130 (2)
S150-S140 (3)
S150-S160
S150-S170
S160-S100
S160-S110
S160-S120
S170-S110

Levy/Citrus (Total = 63 vectors)

C300-C310 (3)
C300-C320
C300-C330
C300-C370
C300-C380
C300-L230 (2)
C300-L260
C300-L270
C310-C340
C310-L230 (2)
C310-L260
C320-C310
C320-C330
C320-C340
C320-C350
C320-C370
C330-C310
C330-C370
C340-C330
C340-C350 (2)
C340-C360
C340-C370 (2)
C350-C360
C350-C370 (2)
C360-C370
C380-C320
C380-C330
C380-C360
L200-L210 (2)
L200-L230
L220-C300
L220-L200
L220-L210
L220-L230 (2)
L220-L250
L230-L260 (2)
L240-L200
L240-L210
L240-L230
L240-L250 (3)
L240-L260
L250-C300
L250-C310
L250-L200
L250-L210
L250-L230
L250-L260
L250-L270
L270-L230 (2)
C310-C370

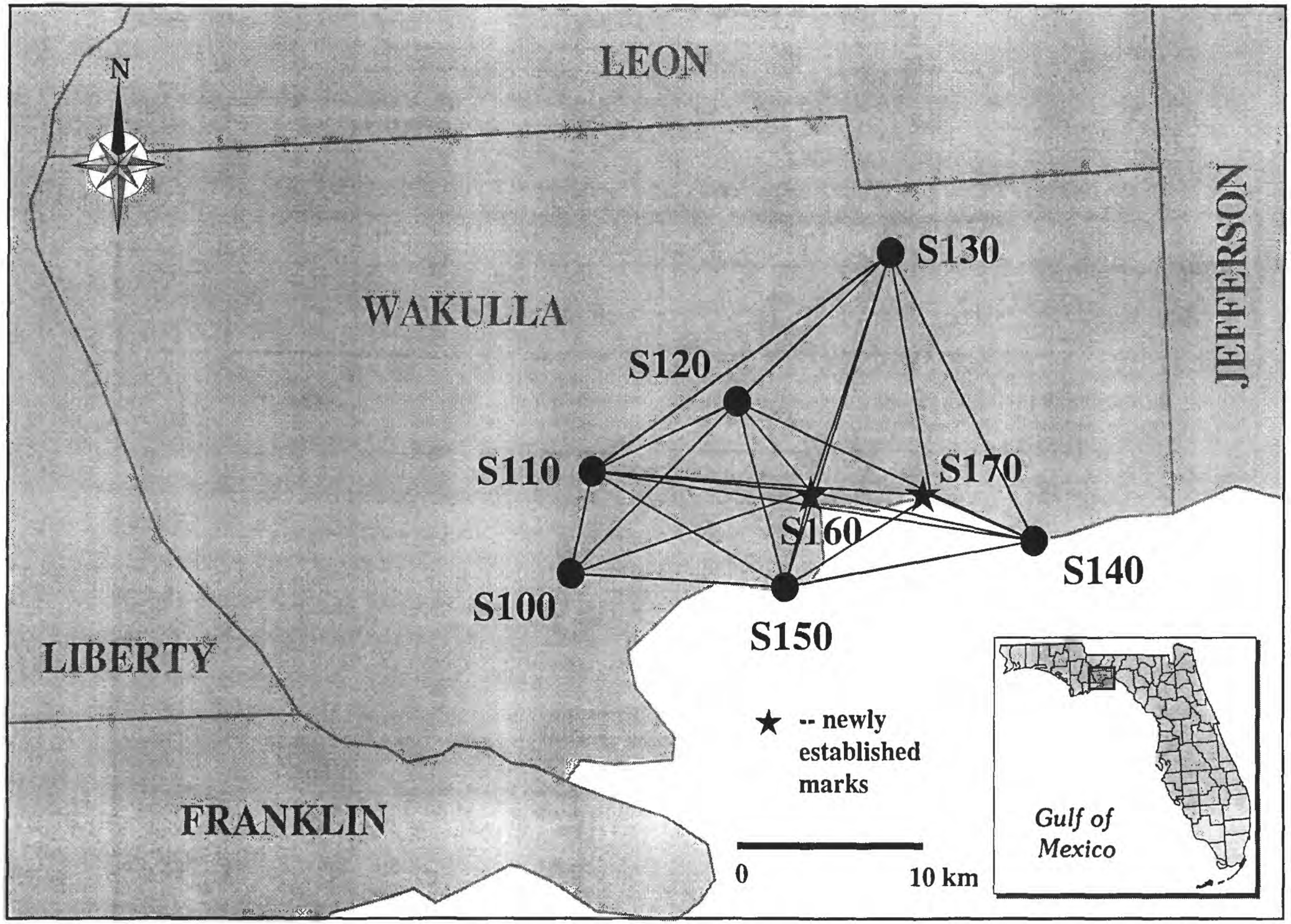


Fig. 4. St. Marks survey network.

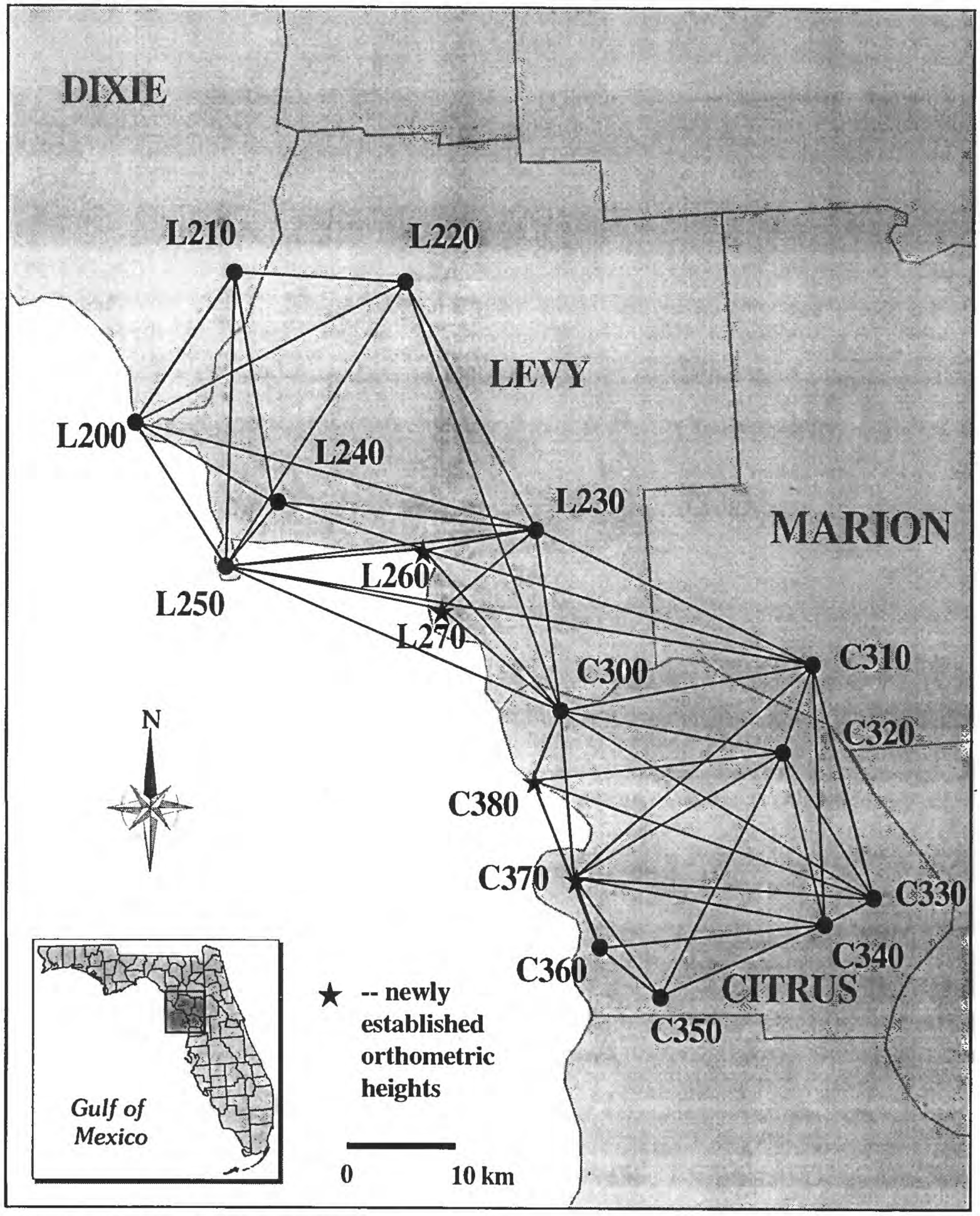


Fig. 5. Network of Levy/Citrus survey.

RECOVERING NEWLY ESTABLISHED MARKS

The following site descriptions are provided as an aid should recovery and reoccupation of these positions be necessary in the future. Several of the sites are only accessible by boat with few landmarks. Use of a small handheld GPS unit to recover the benchmarks is recommended.

St. Marks Survey

S160 -- Wakulla Beach -- From the bridge over the St. Marks River in Newport, head west on U.S. Highway 98 for 4.3 miles to the bridge over the Wakulla River. Continue west on Highway 98 for 1.2 miles to a sand crossroad. Turn left onto the sand crossroad and head south for approximately 4 miles to Wakulla Beach. At the red "Wakulla Beach" sign to the right of the road, take the dirt path west that leads to a line of wooden posts. Walk past the wooden posts about 41 feet to a 3/4 inch galvanized pipe with a screw-on cap. The mark is located between two spray-painted wooden stakes and projects four to five inches from the ground. The mark is also located about 6 paces northwest from a change in vegetation between trees and shrub. The Spring Creek 7.5-minute U.S.G.S. quadrangle map may be of some assistance.

S170 -- S.E.T. 4 -- Accessible by boat only (Fig. 6). About 0.15 miles east of the bridge over the St. Marks River at Newport, head south on State Highway 59 about 10 miles to the boat launch on the right hand side before the St. Marks lighthouse. Follow the channel out to day marker number 12 and head up the channel towards the head of the St. Marks River. At day marker number 29, turn the boat 120 degrees to port to the opening in the marsh and head west toward the opening between Sprague Island and Indian Point. Once inside the small channel, turn to starboard and head north to the tip the marsh on the right of the field instrument. Watch for oyster bars at low tides. S.E.T. 4 will be the first platform reached through the black needlerush (or Juncus) (Fig. 7a). Site S170 is the S.E.T. pipe in the middle of the parallel boardwalks and projects approximately 20 centimeters from the marsh surface. Sixty degrees from north is the GPS measurement point on the edge of the pipe (Fig. 7b). This site is being used for other research. *DO NOT STEP ON THE MARSH SURFACE BETWEEN THE BOARDWALKS.* To survey this point, an eight foot solid wooden board should be placed between the two boardwalks. Contact the authors prior to visiting this site. The Sprague Island 7.5-minute quadrangle map is valuable for the trip.

Levy/Citrus Survey

L260 -- Wacca Azimuth 1934 -- Accessible by boat only. From Gulf Hammock on U.S. Highway 19, head south on State Highway 326 about 3 miles to the boat ramp on Weak Ivy Creek at Williams Camp. Head 3 miles down the Waccasassa River to Lone Cedar Island at the mouth (Fig. 8). The mark is on the west side on the island. The station is 175 feet northwest of NOAA benchmark 872 7471 B 1978 and 160 feet south of NOAA benchmark 872 7471 A 1978, 45 feet south of a lone palm tree, and about 2 feet west of a metal witness post. The mark is set in a large concrete mounting projecting from the ground and stamped Wacca Azimuth 1934. Use the Waccasassa Bay 7.5-minute quadrangle map, if needed.

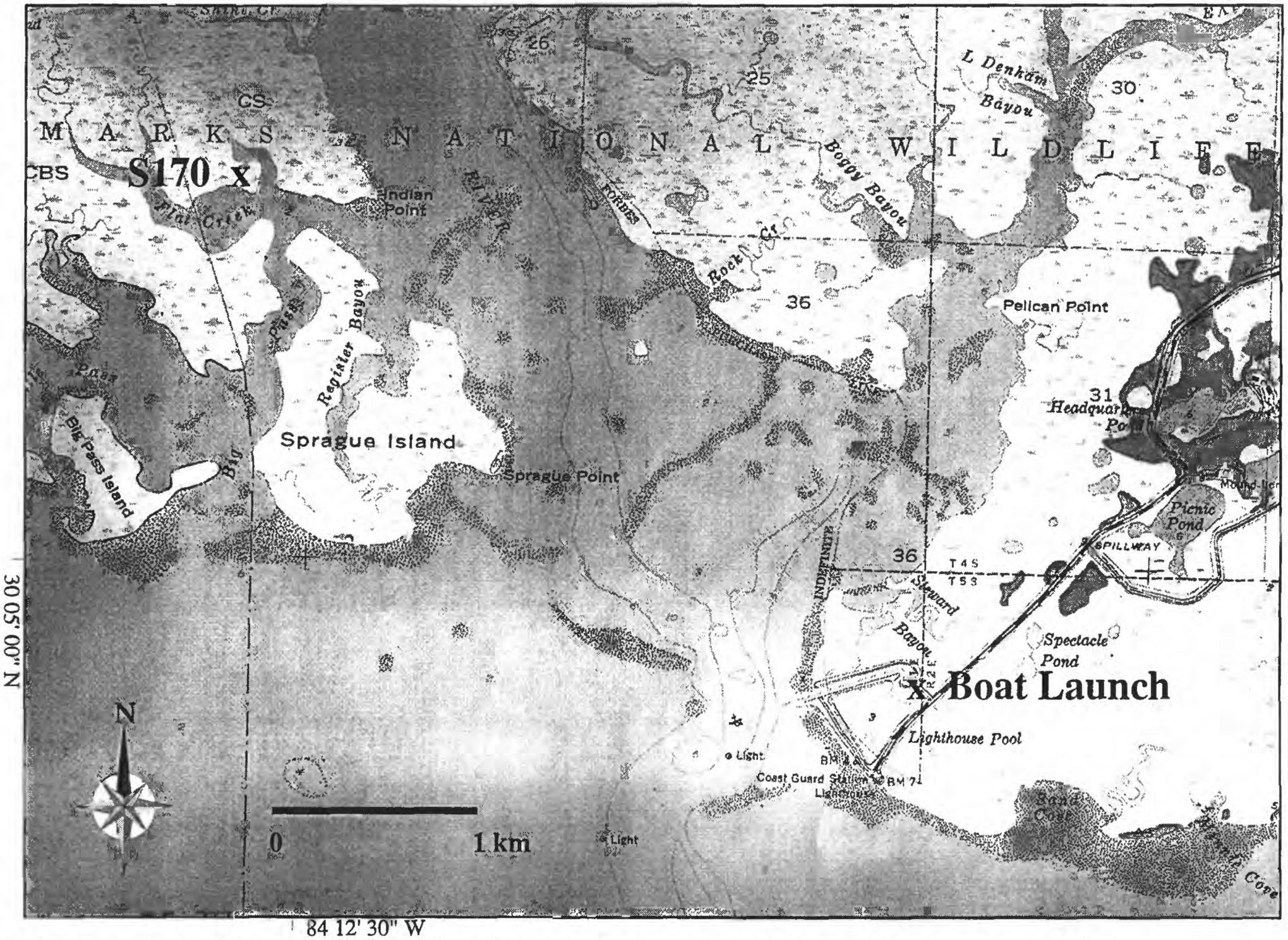
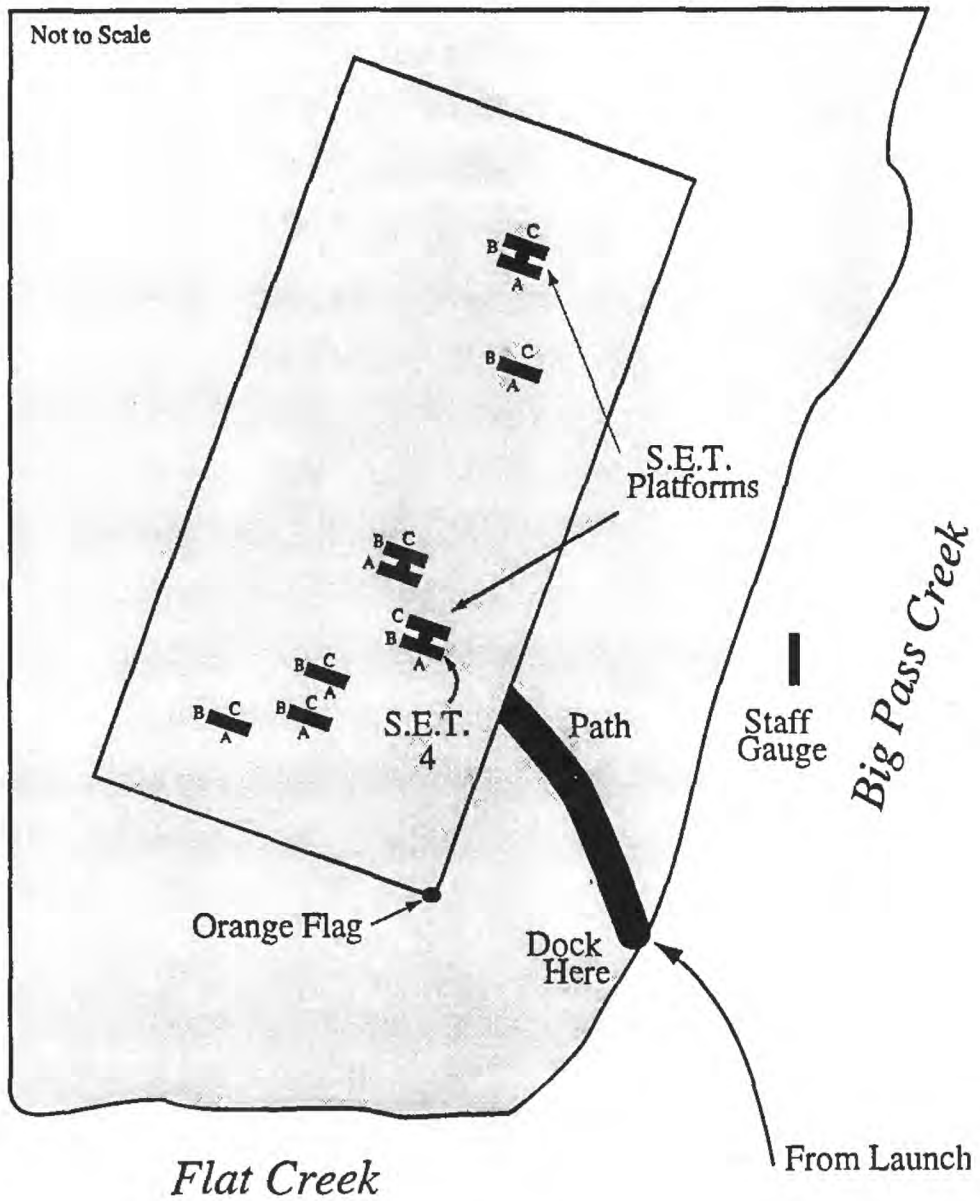


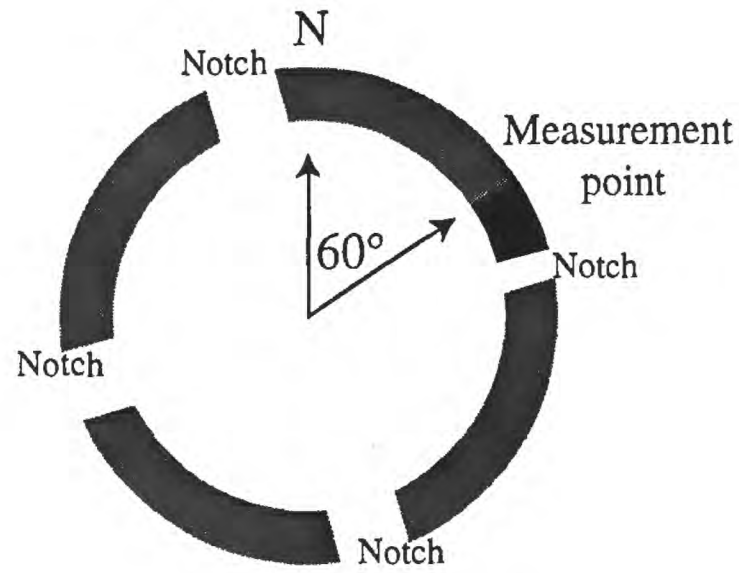
Fig. 6. Sprague Island USGS 7.5-minute topographic map with S.E.T. 4 (S170) set by the NBS.

Fig. 7. Location of S.E.T. 4 (S170) at the NW side of Flat Creek and Big Pass.

A. Each site consists of 2 boardwalks 2 meters apart, with a pipe set in between the walks.



B. Position on pipe of S.E.T. 4.



S.E.T. 4 Pipe

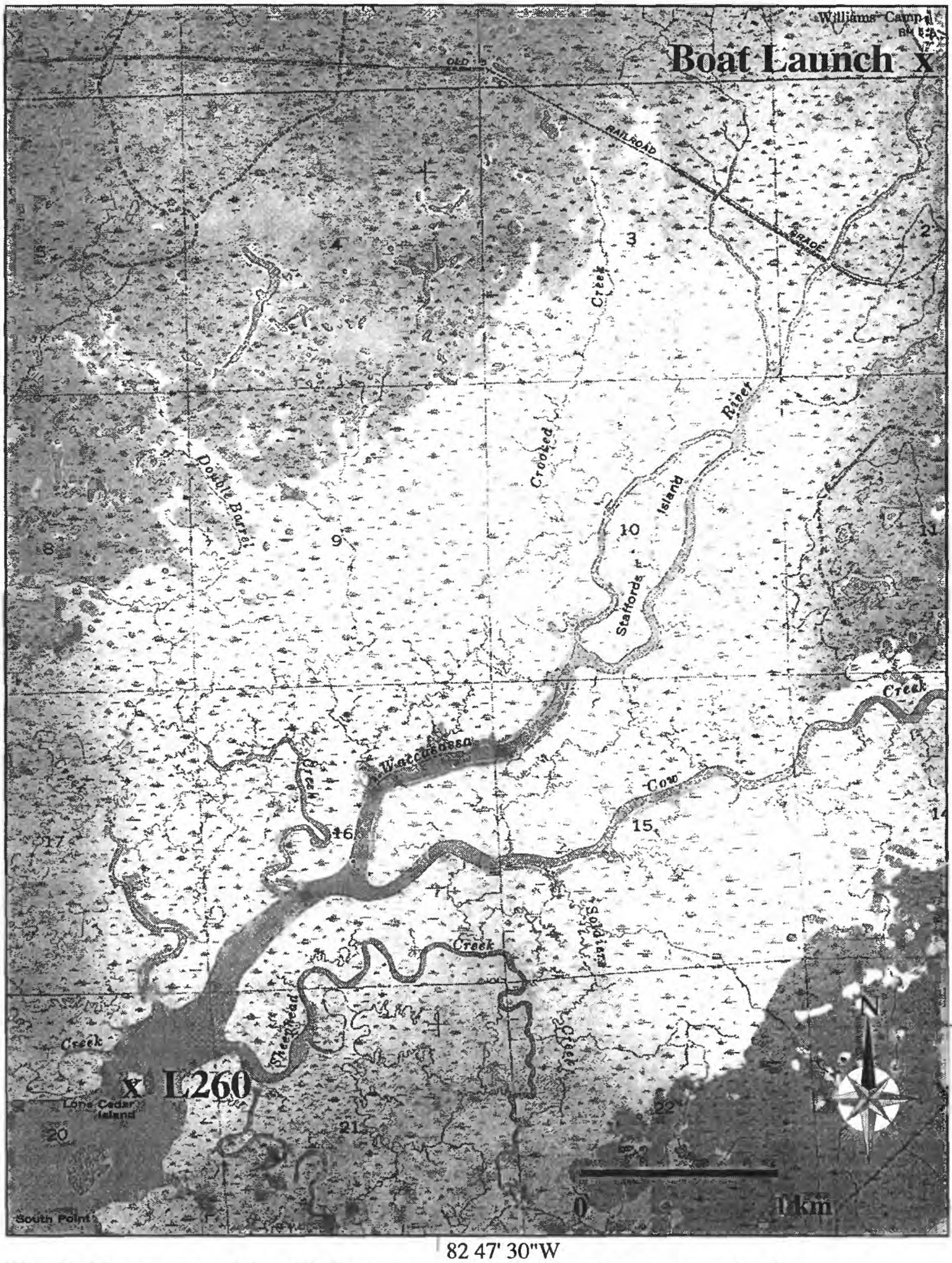


Fig. 8. Waccasassa Bay USGS 7.5-minute topographic map with Wacca Azimuth 1934 (L260).

L270 -- Turtle Creek -- Accessible by boat only. From U.S. Highway 19 at Gulf Hammock, head south on State Road 326 about 3 miles to the boat ramp at Williams Camp. Travel down the Waccasassa River and out into Waccasassa Bay along the coastline to Turtle Creek Bay. Head toward the "island" (hammock) just beyond the confluence of Turtle Creek and Richard Creek (Fig. 9). Dock the boat at the southwest corner of the island. The benchmark is located in low, healthy vegetation off the northwest corner of the island and set in a three to four-inch high concrete mound that is 5 to 6 inches in diameter. An "X" is placed in the top of the mark.

An alternate route to Turtle Creek requires a small manpowered craft such as a canoe and a four wheel drive vehicle to access a private boat launch from approximately two miles east of the mark. Permission to access the boat launch must be obtained from the property owner. This information can be obtained from the Waccasassa State Preserve headquarters in Cedar Key. From U.S. Highway 19 at Inglis head north about one mile to County Road 40A. Turn left and travel one mile to the Gulf Rock Mine sign and turn right onto a sand crossroad. Travel 4.1 miles to a yellow siren (loudspeaker) on top of a pole. Turn left and go 3.5 miles to a pile of boulders on the side of the road. Turn left. At 0.4 miles, veer right to MacDonalds farm and a locked gate. Once inside the gate (permission obtained), veer left 0.3 miles after the farm and travel 1.6 miles through a wooded area, a mudflat clearing and then a small wooded area through the swamp to the boat ramp. The Waccasassa Bay and/or Withlacoochee Bay 7.5-minute quadrangle maps will be useful.

C360 -- 872 7274 TIDAL 4 (relocated) -- From the intersection of U.S. Highway 19 and State Road 490 at Homosassa Springs, head southwest on S.R. 490 to Homosassa Springs Elementary School. From the junction of S.R. 490 and Mason Creek Road at the schoolhouse, proceed southwest along Mason Creek Rd. about two miles to the boat ramp at the end. The benchmark is a 3 inch aluminum casing filled with concrete located approximately 12 meters to the west of the ramp in the marsh. An "X" and "USGS" is marked in the top, and it protrudes about one foot from the marsh surface.

C370 -- 9.332 -- From the intersection of U.S. Highway 19 and County Road 494, head west for 4.85 miles to the mark. The station is set 14 feet southwest of the centerline of C.R. 494, and is set in the northwest abutment of the first bridge over Salt Creek. The mark is stamped as above and is located on the Ozello 7.5-minute quadrangle map.

C380 -- Cedar Creek or CCMP -- Accessible by boat only. From U.S. Highway 19 at Crystal River, head south to the intersection of U.S. 19 and County Road 44. Take C.R. 44 to the end at the Fort Island boat launch. Travel north around Shell Island to the west and head up the Cedar Creek channel to the first large tributary on the left (Fig. 10). The mark is located on the tip of marsh between this tributary and the main channel near the tide gauge. The mark is a 3/4 inch steel rod set in the center of a four inch aluminum pipe filled with concrete. The benchmark is located 26.5 feet from the west corner of the tide gauge dock (corner with antenna and aluminum pole), 7.5 feet north from RM1 (WRD reference marker), 23 feet northwest of high water line at Cedar Creek, and 66 feet and 7 inches southeast from the tributary. The mark projects approximately 1.5 meters from the marsh surface. The Red Level 7.5-minute quadrangle map may be useful.

Using a laser level at C380, the distance and elevation of the Cedar Creek tide gage and reference mark, RM1, was obtained. The tide gage measured approximately 14 meters

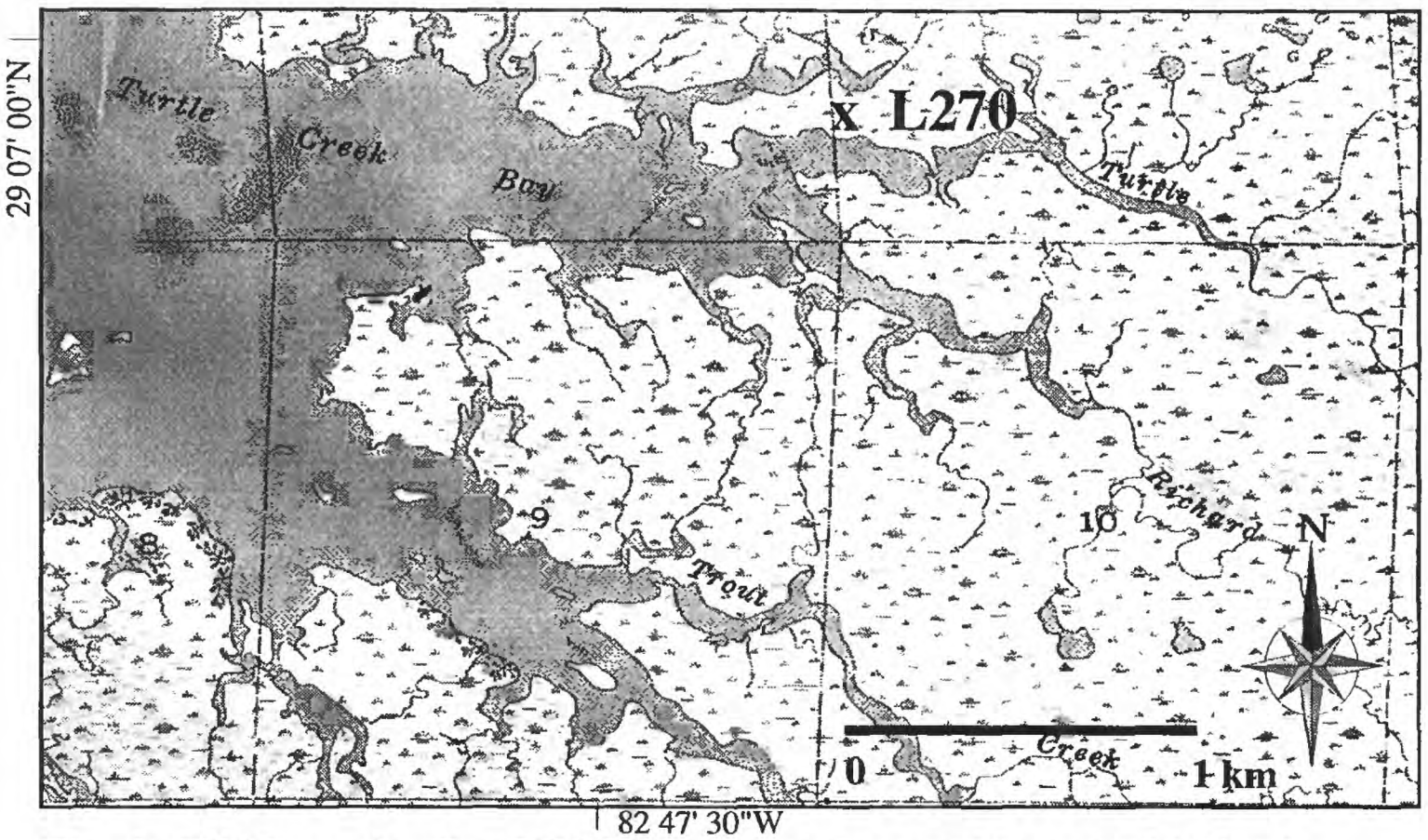


Fig. 9. Withlacoochee Bay USGS 7.5-minute topographic map with Turtle Creek (L270) set on limestone by UF.

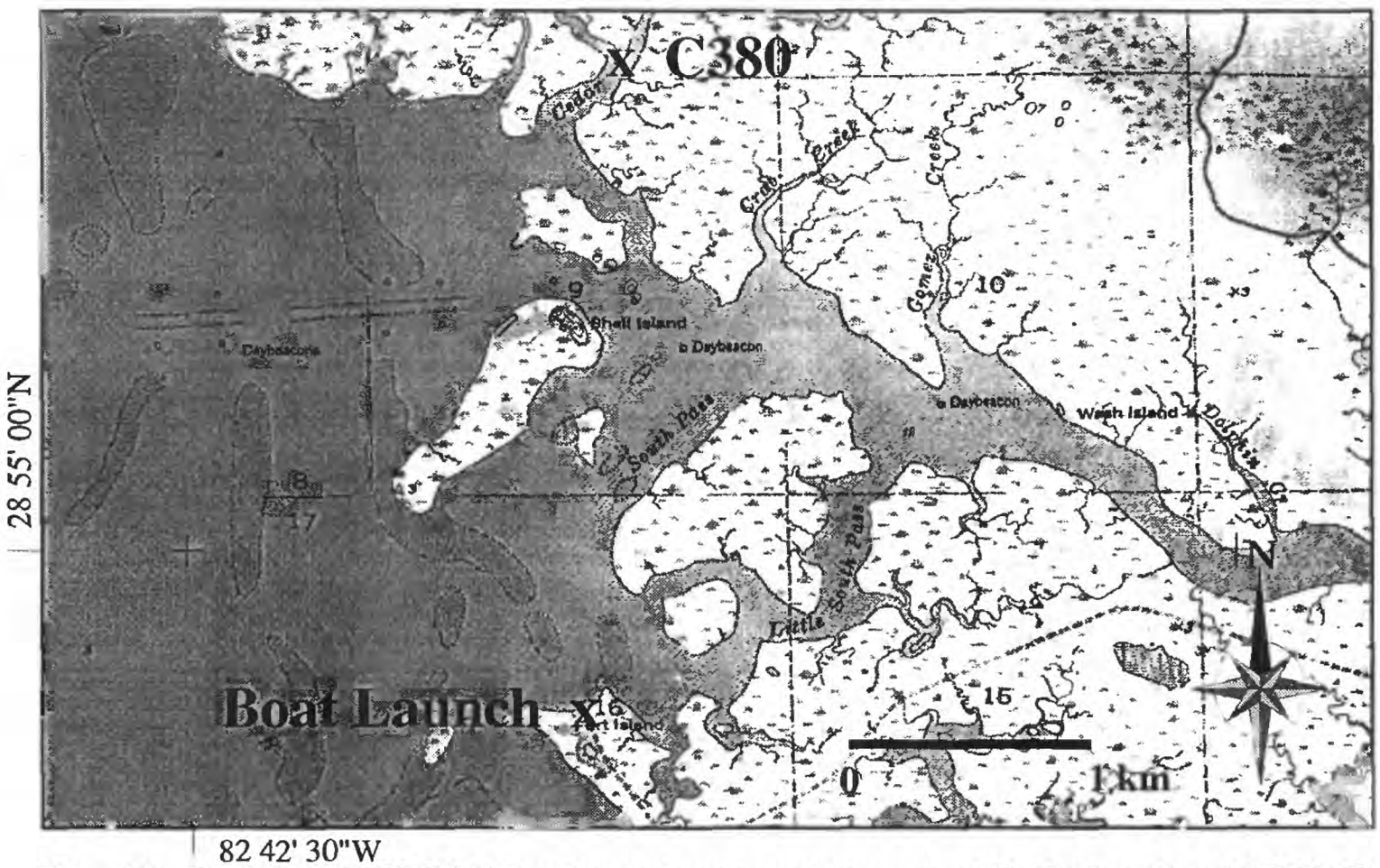


Fig. 10. Red Level USGS 7.5-minute topographic map with Cedar Creek/CCMP (C380) set by the USGS.

from C380 with an elevation of 2.007 meters (NAVD88) at the reference bolt on the gage. The RM1 mark also measured approximately 14 meters from C380 and 1.155 meters lower than the tide gage reference bolt with an orthometric height of 0.852 meters (NAVD88).

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REFERENCES

Federal Geodetic Control Committee, 1988[1989], Standards and Specifications for Geodetic Control Networks: National Geodetic Information Center, NOAA, Rockville, Maryland, 48 p.

Hoffman, Barbara A., 1992, A Characterization of Florida West Coast Salterns: University of South Florida, Tampa, Florida, M.S. Thesis, 61 p.