with water or covered by shallow water at some time during the growing season of each year.

Deepwater habitats are permanently flooded lands lying below the deepwater boundary of wetlands. Deepwater habitats include environments where surface water is permanent and often deep, so that water, rather than air, is the principal medium within which the dominant organisms live, whether or not they are attached to the substrate. As in wetlands, the dominant plants are hydrophytes; however, the substrates are considered nonsoil because the water is too deep to support emergent vegetation (U.S. Soil Conservation Service, Soil Survey Staff, 1975).

Because the fundamental objective of the GBNEP project was to determine the trends and status of wetlands in the Galveston Bay system using aerial photographs, classification and definition of wetlands are integrally connected to the photographs and the interpretation of wetland signatures. Wetlands were not defined nor mapped in accordance with the *Federal Manual for Identifying and Delineating Jurisdictional Wetlands*, which is currently being revised.

METHODS

Mapping and Analyzing Status and Trends

The Galveston Bay project area is defined by 30 U.S. Geological Survey (USGS) 7.5-minute quadrangles (quads) (fig. 2). Status and trends of wetlands in the Galveston Bay system were determined by analyzing the distribution of wetlands mapped on aerial photographs taken in the 1950's, 1979, and late 1980's. Only the late-1980's wetlands maps were completed as part of this project. Maps of the 1950's and 1979 were prepared as part of the USFWS-sponsored Texas Barrier Island Ecological Characterization study (Shew and others, 1981) by Texas A&M University and the National Coastal Ecosystems Team of the USFWS. Final maps of the 1979 series were prepared under the National Wetlands Inventory program. Maps of the 1950's and 1979 series were digitized and initially analyzed in 1983 (USFWS, 1983).

Interpretation of Wetlands

Wetlands for all maps (1950's, 1979, and 1980's) were delineated on aerial photographs through stereoscopic interpretation using procedures developed for the USFWS National Wetlands Inventory program. Field reconnaissance is an integral part of the interpretation process. Photographic signatures were compared to the appearance of wetlands in the field by observing vegetation, soil, hydrology, and topography. This information is weighted for seasonality and conditions existing at the time of photography and ground truthing. Extensive field surveys of wetlands were conducted as part of this study in support of the 1980's delineations (see discussions on field investigations and wetland plant communities). Still, field-surveyed sites represent only a small percentage of the thousands of areas (polygons) delineated. Most areas are delineated on the basis of photointerpretation alone, and misclassifications may occur.

The following explanation is printed on all wetland maps that were used in this project to determine the trends and status of wetlands in the Galveston Bay system:

> This document (map) was prepared primarily by stereoscopic analysis of high-altitude aerial photographs. Wetlands were identified on the photographs based on vegetation, visible hydrology, and geography in accordance with "Classification of Wetlands and Deepwater Habitats of the United States" (FWS/OBS–79/31 December 1979). The aerial photographs typically reflect conditions during the specific year and season when they were taken. In addition, there is a margin of error inherent in the use of the aerial photographs. Thus, a detailed on the ground and historical analysis of a single site may result in a revision of the

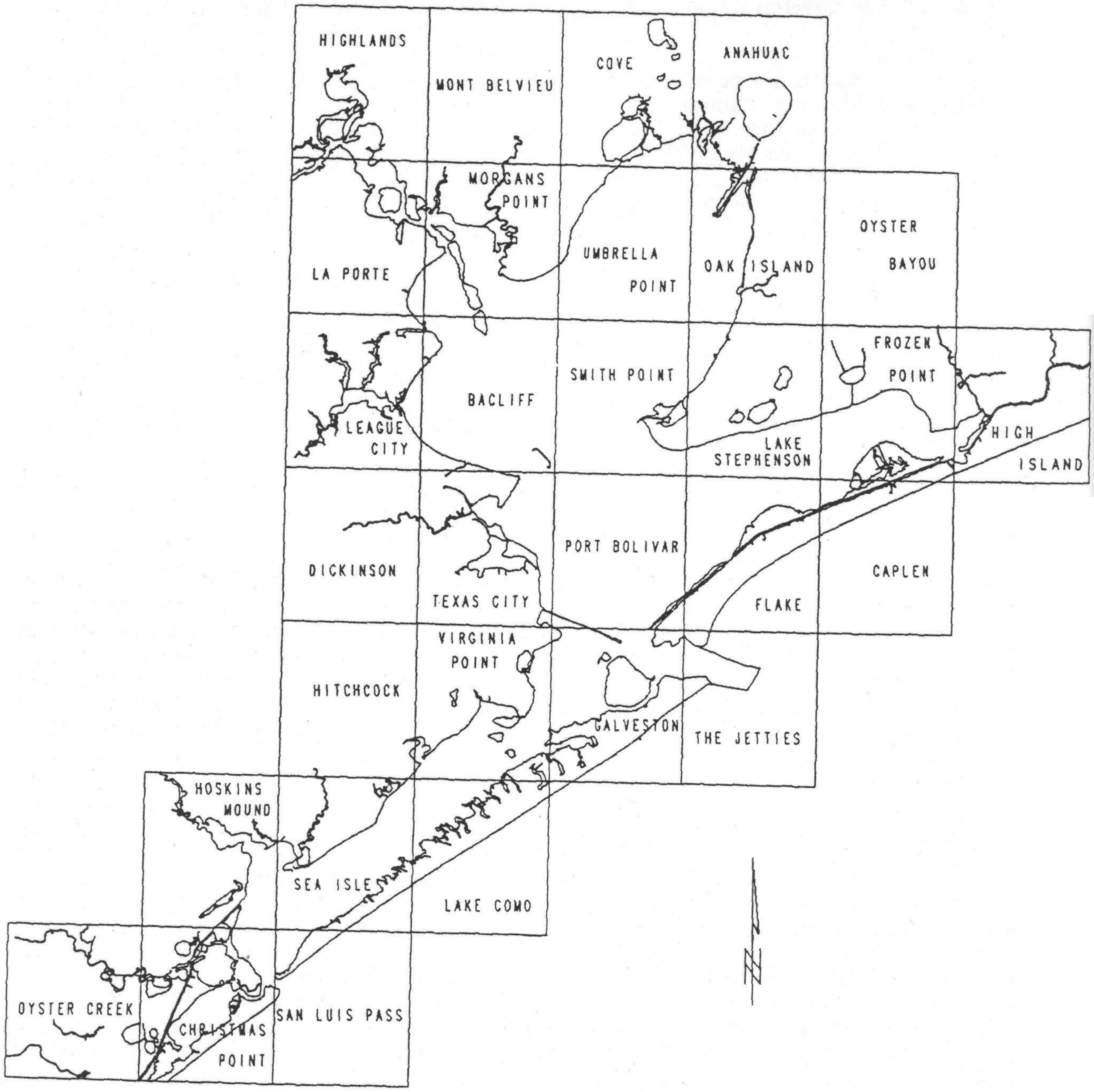


Figure 2. Study area defined by 30 USGS 7.5-minute quads. Map scale is same as figure 1.

wetland boundaries established through photographic interpretation. In addition, some small wetlands and those obscured by dense forest cover may not be included on this document.

Federal, State, and local regulatory agencies with jurisdiction over wetlands may define and describe wetlands in a different manner than that used in this inventory. There is no attempt in either the design or products of this inventory to define the limits of proprietary jurisdiction of any Federal, State or local government or to establish the geographical scope of the regulatory programs of government agencies. . .

Photographs

The 1950's photographs are black-and-white stereo-pair, scale 1:24,000, from the U.S. Department of Agriculture; most were taken in 1952 and 1953, but a few were taken in 1957. The 1979 photographs are NASA color-infrared stereo-pair, scale 1:62,500, taken in November. Late-1980's photographs are NASA color-infrared stereo-pair, scale 1:62,500. Most of the late-1980's photographs used for mapping wetlands were taken in December 1989, but a few that were used in this project were taken in November 1987 and 1988. For simplification in this report, the year 1989 is used when referring to the late-1980's photographs and maps.

Photographs taken in 1979 and 1989 are of high quality, overall. Tidal conditions, however, varied widely. Higher than normal tides were "captured" in 1979, and lower than normal in 1989 (1987 photographs reflected higher tides than in 1989). In addition, abnormally high precipitation in 1979 raised water levels in wetlands. These differences affected certain habitats and their interpreted, or mapped, water regimes. For example, photointerpreted regularly flooded marshes are, in general, more extensive on the 1979 maps than the 1989 maps. Also, many areas mapped as intertidal flats on 1989 photographs were submerged in 1979 and mapped as open water. These flats can be identified on 1989 maps by the water-regime modifier assigned to them.

Although the 1950's photographs are black and white, they are at a large scale (1:24,000), which aids in the photointerpretation and delineation process. The influence of the severe drought that characterized the mid-1950's in Texas (Riggio and others, 1987) apparently had not influenced the Upper Texas Coast in 1952 and 1953 (Dallas Morning News, 1981), the years when most of the 1950's photographs were taken. In fact, a review of some of the 1952 photographs of the Hoskins Mound area indicate abnormally high water levels in some fresh marsh systems. These higher water levels affected the interpretation of wetland habitats, and some peripheral upland areas were mapped as wetlands. In some areas, uplands were misinterpreted and mapped as wetlands. Accordingly, 1950's wetland (marsh) acreages for some areas reflect a larger inland wetland system than actually existed. Problems in photointerpretation are discussed more thoroughly in the section titled "Trends in Wetland Habitats."

Maps

From the photointerpretations, draft maps were prepared, distributed for review, and field checked. Final maps were prepared by transferring lines delineated on aerial photographs to USGS 7.5-minute quadrangle base maps, scale 1:24,000, using Zoom-Transfer Scopes. As in the photointerpretation process (discussed more thoroughly in a following section of photointerpretation errors), there is a margin of error involved in the transfer process. Transfers to maps were completed by a different contractor for the 1950's photographs than for the 1979 and 1989 photographs. Accordingly, a higher degree of standardization and consistency was achieved in the 1979 and 1989 map series.

On 1979 and 1989 maps, wetlands are classified by system, subsystem, class, subclass (for vegetated classes), water-regime, and special modifier in accordance with Cowardin and others (1979) (figs. 3–5). For the 1950's maps, wetlands are classified by system, subsystem, and class. On the 1979 and 1989 maps, upland areas were also mapped and classified by upland habitats using a modified Anderson and others (1976) land-use classification system (fig. 5). Flats and beach/bar classes designated separately on 1950's and 1979 maps were combined into a single class, unconsolidated shore, on 1989 maps (fig. 5).

Thirty 7.5-minute quads make up the Galveston Bay Project area (fig. 2). Delineations for the 1989 maps were digitized and entered into the geographic information system (GIS) ARC/INFO for analysis on a quad by quad basis. GIS data files previously digitized and maintained by the USFWS for the 1950's, and 1979 photographs were obtained and translated to digital line graph (DLG) format in a form readable by ARC/INFO.

The digitizing process is a means of data capture of the lines, points, and polygons displayed on hard-copy maps. Data are captured with a digitizing tablet using a software package called the Analytical Mapping System (AMS). The AMS is a menu-driven geographically referenced digitizing system that contains predefined, sequential data-entry procedures, including: map preparation and georeferencing; digitizing and editing; polygon verification/formation; and data base construction and transfer. The base map to be digitized is registered to a geographic referencing system with AMS by establishing the longitude and latitude registration marks (maximum 16, minimum 8) of the map as points within the digitizing tablet grid and the latitude/longitude registration points of the map. These values are either accepted or declined by the digitizer in compliance with national map-accuracy standards. The data are digitized and stored in an arc-mode format. AMS provides internal verification of polygon closure, island formation, and edge matching. Quality control is performed within AMS to identify errors in attribute assignment, open polygons, crossing line segments, unattached edge modes, or misassigned islands. Additional quality control is done by the digitizer who produces a plot of the digitized data and compares it to the original map. This provides a check for errant lines, missed polygons, missing lines, or lines that diverge from the original in location, direction, or directness. Following editing and verification, the digital map data are transferred to a permanent AMS data base and can be exported to the Map Overlay and Statistical Subsystem (MOSS) or to ARC/INFO for analysis of the data.

Results include GIS data sets consisting of electronic-information overlays corresponding to mapped habitat features for the 1950's, 1979, and 1980's. The data can be manipulated as information overlays, whereby scaling and selection features allow portions of the estuary to be electronically selected for specific analysis.

Among the objectives of the geographic information system are: (1) to allow direct historical comparisons of habitat types to gauge historical trends and status of estuarine habitat, (2) to allow novel comparisons of feature overlays to suggest probable causes of wetland changes, (3) to make information on wetlands directly available to managers in a convenient and readily assimilated form, and (4) to allow overlays to be combined from both this and future studies on other topics in a single system that integrates disparate environmental features for purposes of creating a Comprehensive Conservation and Management Plan (CCMP). The GIS is expected to become a flexible and valuable management tool for future use by resource agencies.

Field Investigations

Field investigations were conducted for two related purposes: (1) to characterize wetland plant communities through representative field surveys and (2) to compare various wetland plant communities in the field with corresponding "signatures" on aerial photographs used to define wetland classes, including water regimes, for mapping purposes. All field work was done with reference to aerial photographs (1979 or 1989). Characterization of prevalent plant associations

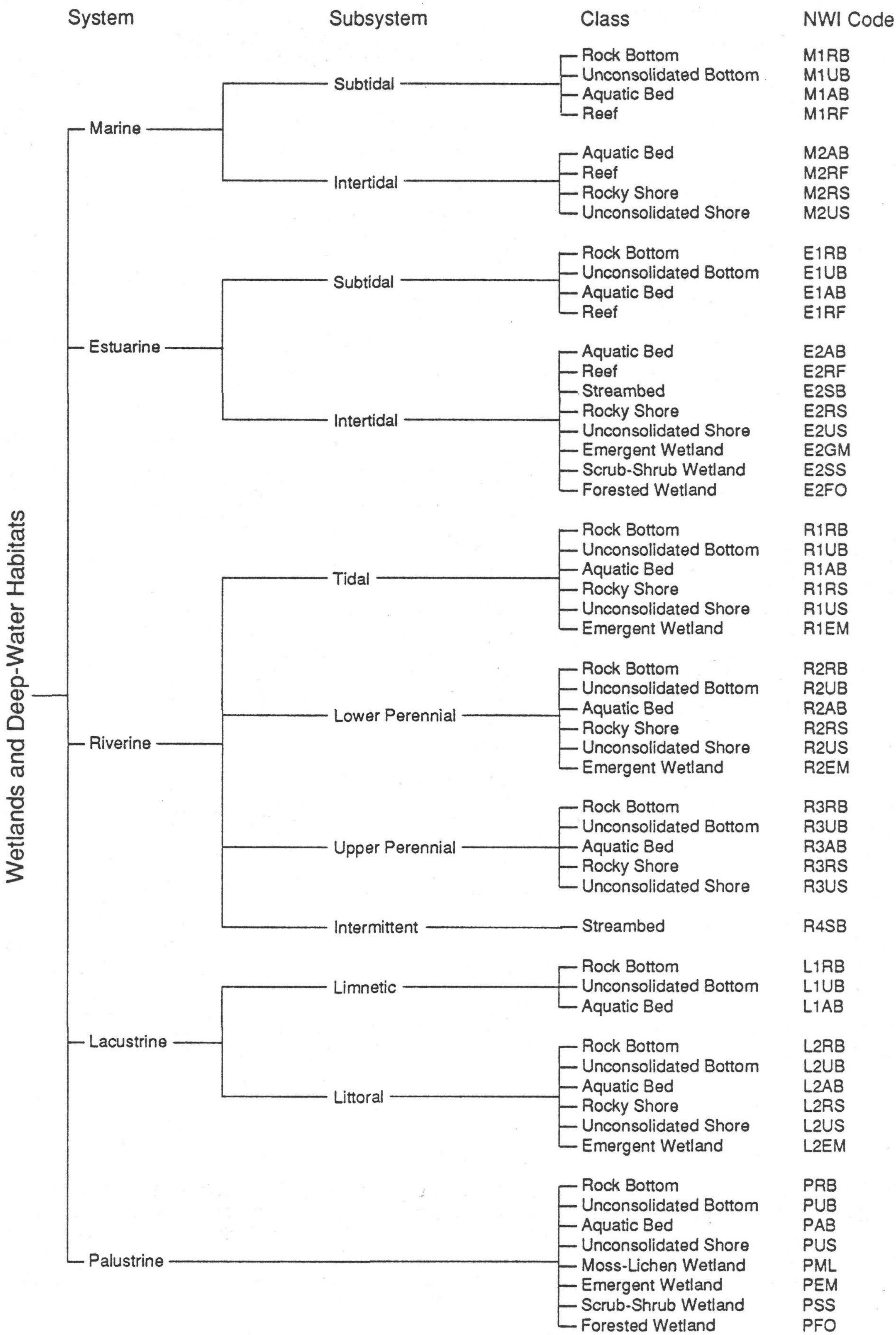


Figure 3. Classification hierarchy of wetlands and deepwater habitats showing systems, subsystems, and classes. From Cowardin and others (1979).

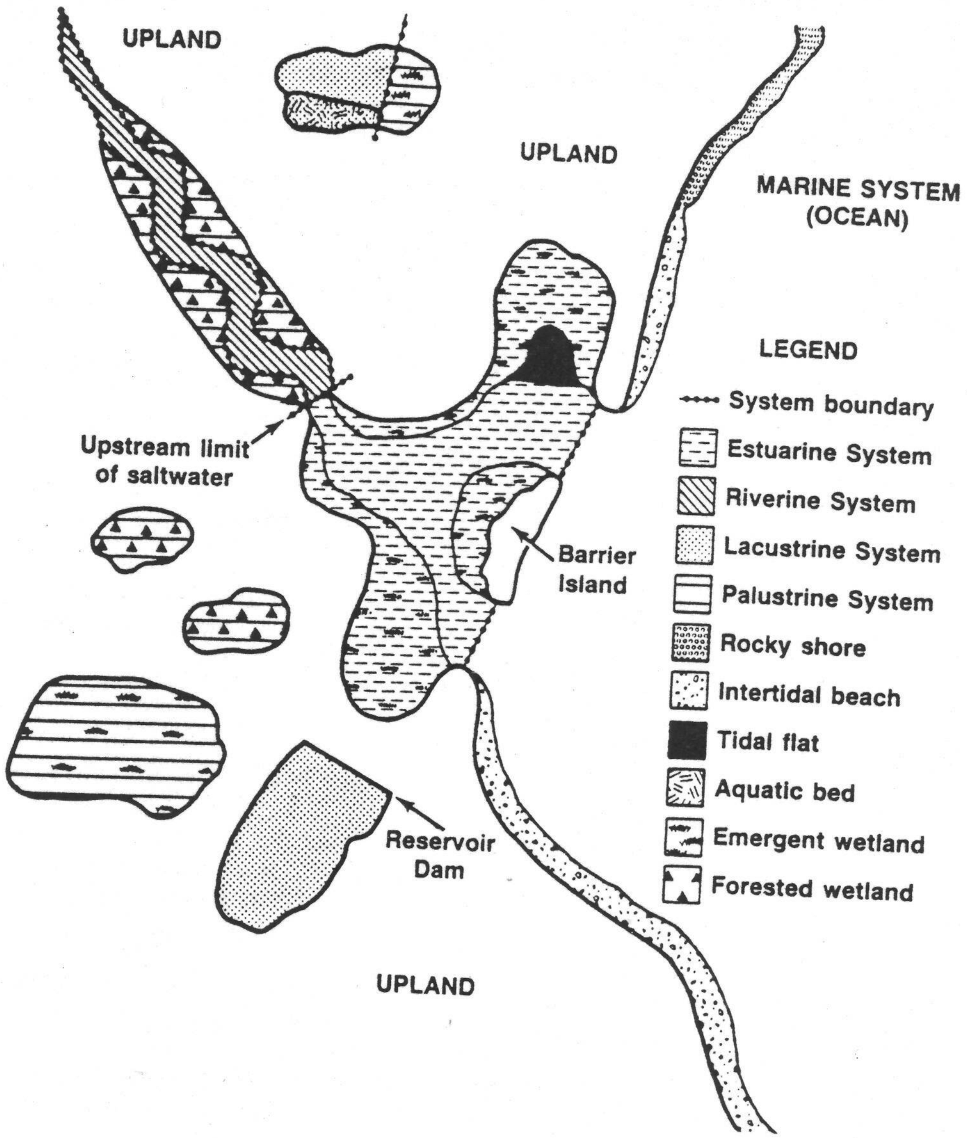
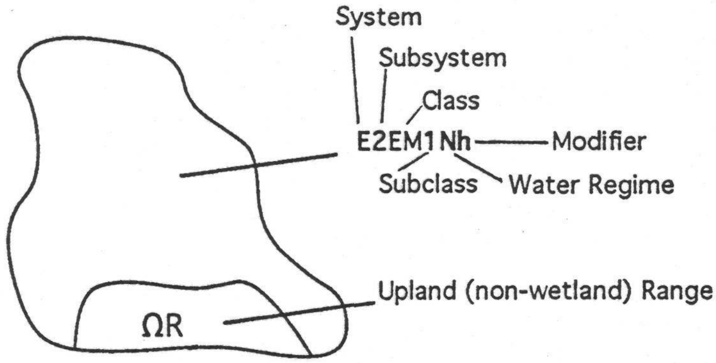


Figure 4. Schematic diagram showing major wetland and deepwater habitat systems. From Tiner (1984).

Symbology example



Upland Legend

Upland Classes	Modifying Terms
U-Urban or Developed	o-oil and/or gas
A-Agricultural	r-rice field
F-Forest	6-deciduous 7-evergreen
SS-Scrub/Shrub	8-mixed
R-Range	s-spoil d-dune
B-Barren	t-transportation

Changes in Class Symbols

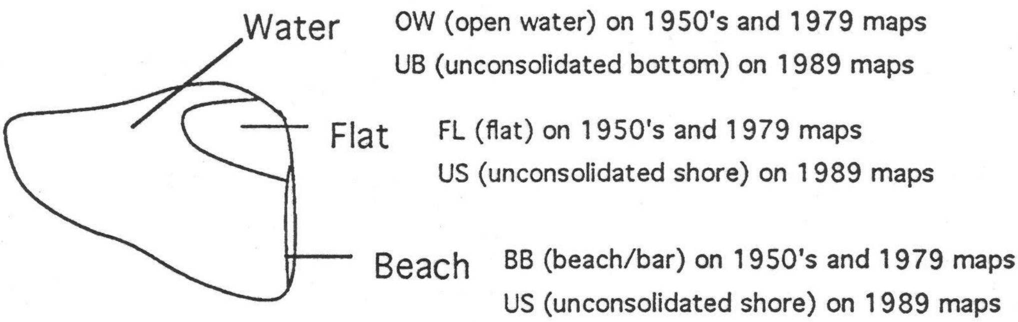


Figure 5. Example of symbology used to define wetland and upland habitats on National Wetland Inventory maps.

(White and Paine, 1992) provided vital plant community information for defining mapped wetland classes in terms of typical vegetation associations.

During field surveys, prevalent plant species associations were characterized "within the constraints imposed by the resolution of the photos" (as stated in the Project Scope of Work, 1990). More than 180 sites were examined in the Galveston Bay system. Many more sites were surveyed in less detail during the process of ground-truthing delineations on photographs and draft maps. Only the most recent aerial photographs were "ground truthed." Ancillary information used in the field and in photointerpretation included topographic maps, soil surveys, lists of hydrophytes and hydric soils, and consultation with field experts about wetland communities, water management practices, impoundments, and rice cultivation.

Survey sites included the Brazoria and Anahuac National Wildlife Refuge, Armand Bayou Nature Center, Follets and Galveston Islands, Bolivar Peninsula, Smith Point, High Island area, Trinity River delta, and other areas. Plant communities were surveyed during the months of June, July, and November, 1990, and May and September, 1991. Personnel, other than the authors, involved in one or more field surveys included Warren Hagenbuck and Curtis Carley (USFWS–National Wetlands Inventory), Todd Mecklenborg (Geonex Martel, Inc.), Melvin Fuhrmann (USFWS–National Wetlands Research Center), Jeff Paine (Bureau of Economic Geology), and Warren Pulich (Texas Parks and Wildlife Department). In addition, Ron Bisbee (Refuge Manager), Richard Antonette, and Mike Lange of the Brazoria National Wildlife Refuge, and Jim Neaville and Ed Jackson of the Anahuac National Wildlife Refuge accompanied field parties to their respective areas.

During the initial field investigations, methods were developed to characterize prevalent species associations. The primary method was one in which wetland plants were identified at selected field survey sites, principally along transects aligned perpendicular to the hydrologic gradient so that plant assemblages from the water's edge to upland areas were intercepted. A second approach was to conduct a topographic survey along selected transects that crossed representative plant communities to identify relative elevations at which various plant species occur. This is helpful in defining water regimes and in differentiating between high and low marsh communities. The boundaries between some plant assemblages are controlled in part by elevation, so elevation measurements focus on such boundaries. Plant species that were difficult to identify in the field were collected for identification in the laboratory or with reference to the plant collection at The University of Texas Herbarium. References used in plant identification were Correll and Correll, 1975; Correll and Johnston, 1970; Texas Forest Service, 1963; Gould, 1975; and Fleetwood, no date, among others.

Topography surveys were conducted along several transects. Measurements of elevation, distance, and plant community composition were made along the survey lines, which crossed salt marshes (Smith Point, Follets Island, and mainland margin of West Bay) and brackish to fresh marshes (Anahuac National Wildlife Refuge, Brazoria National Wildlife Refuge, and Trinity River delta). Elevations were measured to the nearest 0.5 cm and distances were measured to the nearest meter. Compass bearings of the transects were also recorded.

County soil surveys (Brazoria County, Crenwelge and others, 1981; Chambers County, Crout, 1976; Galveston County, Crenwelge and others, 1988; and Harris County, Wheeler and others, 1976) were used to define and characterize soils at the various field check sites. Information obtained from the soil surveys included soil type, salinity, drainage, frequency of flooding, position of water table, and prevalent vegetation.

The locations of field survey sites were plotted on aerial photographs, and later accurately transferred to USGS 7.5-minute quadrangle topographic maps using a Zoom Transfer Scope where necessary. Universal Transverse Mercator (UTM) coordinates were determined for each site and these data were entered into computer data management systems, including the GIS, ARC/INFO.