

Local Gains in Wetlands

- Losses in emergent wetlands in some areas were partly offset by gains in emergent wetlands in other areas. Conversion of uplands to emergent wetlands, in part due to subsidence, accounted for an increase of about 21,000 acres. Additional increases in emergent wetlands resulted from the spread of emergent vegetation over areas previously mapped as intertidal flats.
- Although newly established wetlands provide some measure of areal offset to net wetland loss, there is not necessarily a corresponding offset in terms of functional value. Some researchers suggest that several years of development may be necessary for newly formed marshes to reach overall functional equivalency to older marshes (Minello and Zimmerman, 1992). It is possible that they may never become totally equivalent.
- The declining rate of loss of wetlands over the more recent period (1979–1989), coupled with local gains in wetland habitats in some areas, provide a cautionary measure of hope that planning and proper management of wetlands can help mitigate the trend toward net loss of these valuable resources in the Galveston Bay system.

ACKNOWLEDGMENTS

This study was sponsored by the Galveston Bay National Estuary Program, funded by the U.S. Environmental Protection Agency under assistance agreement with the Texas Water Commission.

Numerous people were involved in various phases of this study. The authors would like to recognize Todd Mecklenborg of Geonix Martel who was the primary aerial photo interpreter for all wetland and upland habitats delineated on 1989 photographs. Other personnel from the U.S. Fish and Wildlife Service that had major roles in photointerpretation and field checking 1989 delineations on photographs and draft maps, included Larry Handley (National Wetlands Research Center) and Curtis Carley and Warren Haggenbuck (National Wetlands Inventory). Others involved in fieldwork included Bill White and Jeff Paine (Bureau of Economic Geology), Warren Pulich (Texas Parks and Wildlife Department), and Melvin Fuhrmann (USFWS–National Wetlands Research Center). Field support from local USFWS Wildlife Refuges was provided by Jim Neaville and Ed Jackson of the Anahuac National Wildlife Refuge, and Ron Bisbee, Mike Lange, and Richard Antonette of the Brazoria National Wildlife Refuge.

The authors wish to thank the following scientists who reviewed the draft report and provided helpful comments that improved the quality of the final report: Donald Moore (National Marine Fisheries Service and GBNEP designated reviewer), Thomas Calnan (General Land Office), Albert Green (Texas Parks and Wildlife Department), Bill Jackson (National Marine Fisheries Service), Geoffrey Matthews (National Marine Fisheries Service), Kenneth Teague (Environmental Protection Agency), Eddie Seidensticker (Soil Conservation Service), James Webb (Texas A&M University at Galveston), and Roger Zimmerman (National Marine Fisheries Service). The authors also recognize Russell Kiesling (Research Administrator of GBNEP) for his help with the Executive Summary.

Special thanks go to personnel of the Bureau of Economic Geology who helped in the preparation of this report. Assistance with figures and photographs was provided by Richard L. Dillon, Chief Cartographer, and David Stephens. Paste-up of figures was completed by Jamie H. Coggin and Margaret L. Evans. Editing was by Kitty Challstrom and Amanda R. Masterson, and final word processing was by Susan Lloyd.

REFERENCES

- Anderson, J. R., Hardy, E. E., Roach, J. T., and Witmer, R. E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 27 pp.
- Baumann, R. H., 1980, Mechanisms of maintaining marsh elevation in a subsiding environment: Louisiana State University, Master's thesis, 92 pp.
- Baumann, R. H., and DeLaune, R. D., 1982, Sedimentation and apparent sea-level rise as factors affecting land loss in coastal Louisiana, *in* Boesch, D. F., ed., Proceedings of the conference on coastal erosion and wetland modification in Louisiana: causes, consequences, and options: U.S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-82/59, p. 2-13.
- Benton, A. R., Jr., Snell, W. W., and Clark, C. A., 1979, Monitoring and mapping of Texas coastal wetlands, Galveston Bay and Sabine Lake areas, 1978 growing season: College Station, Texas A&M University, Remote Sensing Center, technical report RSC-102, 123 pp.
- Bernard, H. A., Major, C. F., Jr., and Parrott, B. S., 1959, The Galveston barrier island and environs: a model for predicting reservoir occurrence and trend: Gulf Coast Association of Geological Societies Transactions, v. 9, p. 221-224.
- Bodine, B. R., 1969, Hurricane surge frequency estimated for the Gulf Coast of Texas: U.S. Army Corps of Engineers, Coastal Engineering Research Center Technical Memorandum 26, 32 pp.
- Boesch, D. F., Levin, D., Nummedal, D., and Bowles, K., 1983, Subsidence in coastal Louisiana: causes, rates, and effects on wetlands: U.S. Fish and Wildlife Service, Division of Biological Services, Washington, D.C., FWS/OBS-83/26, 30 pp.
- Brown, L. F., Jr., Morton, R. A., McGowen, J. H., Kreitler, C. W., and Fisher, W. L., 1974, Natural hazards of the Texas Coastal Zone: The University of Texas at Austin, Bureau of Economic Geology, 13 pp., 7 maps.
- Chabreck, R. H., 1972, Vegetation, water, and soil characteristics of the Louisiana coastal region: Louisiana State University and Agricultural and Mechanical College Bulletin 664, 72 pp.
- Correll, D. S., and Correll, H. B., 1975, Aquatic and wetland plants of southwestern United States: California, Stanford University Press, 2 v., 1777 pp.
- Correll, D. S., and Johnston, M. C., 1970, Manual of the vascular plants of Texas: Texas Research Foundation, Renner, Texas, 1881 pp.

- Cowardin, L. M., Carter, V., Golet, F. C., and LaRoe, E. T., 1979, Classification of wetlands and deep-water habitats of the United States: U.S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services, Washington, D.C., FWS/OBS-79/31, 103 pp.
- Crenwelge, G. W., Crout, J. D., Griffin, E. L., Golden, M. L., and Baker, J. K., 1981, Soil survey of Brazoria County, Texas: U.S. Department of Agriculture, Soil Conservation Service, 182 pp., 36 maps.
- Crenwelge, G. W., Griffin, E. L., and Baker, J. K., 1988, Soil survey of Galveston County, Texas: U.S. Department of Agriculture, Soil Conservation Service, 182 pp., 36 maps.
- Crout, J. D., 1976, Soil survey of Chambers County, Texas: U.S. Department of Agriculture, Soil Conservation Service, 53 pp., 54 maps.
- Dallas Morning News, 1979, Texas almanac and state industrial guide, 1980-1981: A. H. Belo Corporation, Dallas, Texas, 704 pp.
- Dahl, T. E., Johnson, C. E., and Frayer, W. E., 1991, Wetlands, status and trends in the conterminous United States mid-1970's to mid-1980's: U.S. Department of the Interior, U.S. Fish and Wildlife Service, 23 pp.
- DeLaune, R. D., Patrick, W. H., Jr., and Buresh, R. J., 1978, Sedimentation rates determined by ¹³⁷Cs dating in a rapidly accreting salt marsh: *Nature*, v. 275, p. 532-533.
- Diener, R. A., 1975, Cooperative Gulf of Mexico estuarine inventory and study—Texas; area description: National Oceanic and Atmospheric Administration, technical report, National Marine Fisheries Service Circular 393, 129 pp.
- Everett, J. R., and Reid, W. M., 1981, Active faults in the Houston, Texas, area as observed on Landsat imagery, *in* Etter, E. M., ed., Houston area environmental geology: surface faulting, ground subsidence, hazard liability: Houston Geological Society, p. 13-27.
- Fleetwood, R. J., no date, Plants of Brazoria/San Bernard National Wildlife Refuges, Brazoria County, Texas: U.S. Department of the Interior, Fish and Wildlife Service, 61 pp.
- Fisher, W. L., Brown, L. F., Jr., McGowen, J. H., and Groat, C. G., 1973, Environmental Geologic Atlas of the Texas Coastal Zone—Beaumont-Port Arthur Area: The University of Texas at Austin, Bureau of Economic Geology, 93 pp., 9 maps.
- Fisher, W. L., McGowen, J. H., Brown, L. F., Jr., and Groat, C. G., 1972, Environmental Geologic Atlas of the Texas Coastal Zone—Galveston-Houston Area: The University of Texas at Austin, Bureau of Economic Geology, 91 pp., 9 maps.

- Gabrysch, R. K., 1969, Land-surface subsidence in the Houston–Galveston region, Texas: United Nations Educational, Scientific and Cultural Organization (UNESCO), Studies and Reports in Hydrology, Land Subsidence Symposium, v. 1, p. 43–54.
- Gabrysch, R. K., 1984, Ground-water withdrawals and land-surface subsidence in the Houston–Galveston region, Texas, 1906–1980: Texas Department of Water Resources Report 287, 64 pp.
- Gabrysch, R. K., and Bonnet C. W., 1975, Land-surface subsidence in the Houston–Galveston region, Texas: Texas Water Development Board Report 188, 19 pp.
- Gabrysch, R. K., and Coplin, L. S., 1990, Land-surface subsidence resulting from ground-water withdrawals in the Houston–Galveston region, Texas, through 1987: U.S. Geological Survey Report of Investigations No. 90-01, 53 pp.
- Gornitz, V., Lebedeff, S., and Hansen, J., 1982, Global sea level trend in the past century: Science, v. 215, p. 1611–1614.
- Gosselink, J. G., and Baumann, R. H., 1980, Wetland inventories: wetland loss along the United States coast: Z. Geomorph. N.F. Suppl. Bd. v. 34, p. 173–187.
- Gosselink, J. G., Cordes, C. L., and Parsons, J. W., 1979, An ecological characterization study of the Chenier Plain coastal ecosystem of Louisiana and Texas: U.S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-78/9 through 78/11, 3 v.
- Gould, F. W., 1975, Texas plants—a checklist and ecological summary: Texas Agricultural Experiment Station, MP-585/Revised, College Station, Texas, 121 pp.
- Harcombe, P. A., and Neaville, J. E., 1977, Vegetation types of Chambers County, Texas: Texas Journal of Science, v. 29, p. 209–234.
- Hatton, R. S., DeLaune, R. D., and Patrick, W. H., Jr., 1983, Sedimentation, accretion, and subsidence in marshes of the Barataria Basin, Louisiana: Limnology and Oceanography, v. 28, no. 3, p. 494–502.
- Johnston, J. B., and Ader, R. A., 1983, The use of a GIS for Gulf of Mexico wetland change, in Magoon, O. T., and Converse, H., eds., Coastal Zone '83, Volume I: American Society of Civil Engineers, New York, p. 362–371.
- Kreitler, C. W., 1977, Faulting and land subsidence from ground-water and hydrocarbon production, Houston–Galveston, Texas: The University of Texas at Austin, Bureau of Economic Geology Research Notes 8, 22 pp.

- Kreitler, C. W., White, W. A., and Akhter, M. S., 1988, Land subsidence associated with hydrocarbon production, Texas Gulf Coast (abs.): American Association of Petroleum Geologists Bulletin, v. 72, no. 2, p. 208.
- Lazarine, Paul, no date, Common wetland plants of southeast Texas: U.S. Army Corps of Engineers, Galveston District, variously paginated.
- McAtee, J. W., 1976, Autecological aspects of Gulf cordgrass [*Spartina spartinae* (Trin.) Hitchc.] communities of the Texas coastal prairie, in Range ecological and management research on the coastal prairie, progress report of cooperative studies: Sinton, Welder Wildlife Foundation and Texas A&M University, Texas Agricultural Experiment Station, p. 2-12.
- McFarlane, R. W., 1991a, An environmental inventory of the Christmas Bay Coastal Preserve: Galveston Bay National Estuary Program, GBNEP Publication-7, 95 pp.
- McFarlane, R. W., 1991b, An environmental inventory of the Armand Bayou Coastal Preserve: Galveston Bay National Estuary Program, GBNEP Publication-8, 66 pp.
- Minello, T. J., and Zimmerman, R. J., 1992, Utilization of natural and transplanted Texas salt marshes by fish and decapod crustaceans: Marine Ecology Progress Series, v. 90, p. 273-285.
- Morton, R. A., 1977, Historical shoreline changes and their causes, Texas Gulf Coast: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 77-6, p. 352-364.
- Morton, R. A., and Paine, J. G., 1990, Coastal land loss in Texas—an overview: Gulf Coast Association of Geological Societies Transactions, v. 40, p. 625-634.
- Mullican, W. F., III, 1988, Subsidence and collapse at Texas salt domes: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 88-2, 36 pp.
- Oenema, Oene, and DeLaune, R. D., 1988, Accretion rates in salt marshes in the Eastern Scheldt, southwest Netherlands: Estuarine, Coastal and Shelf Science, v. 26, p. 379-394.
- Orlando, S. P., Kein, C. J., Rozas, L. P., and Ward, G. H., 1991, Salinity characterization of Galveston Bay, in Shipley, F. S., and Kiesling, R. W., eds., Proceedings of the Galveston Bay characterization workshop: Galveston Bay National Estuary Program, GBNEP Publication-16, p. 179-185.
- Paine, J. G., and Morton, R. A., 1986, Historical shoreline changes in Trinity, Galveston, West, and East Bays, Texas Gulf Coast: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 86-3, 58 pp.

- Penfound, W. T., and Hathaway, E. S., 1938, Plant communities in the marshlands of southeastern Louisiana: Ecological Monographs, v. 8, no. 1, 56 pp.
- Penland, Shea, Ramsey, K. E., McBride, R. A., Mestayer, J. T., and Westphal, K. A., 1988, Relative sea level rise and delta-plain development in the Terrebonne Parish region: Baton Rouge, Louisiana Geological Survey, Coastal Geology Technical Report no. 4, 121 pp.
- Pratt, W. E., and Johnson, D. W., 1926, Local subsidence of the Goose Creek oil field: Journal of Geology, v. 34, p. 577-590.
- Pulich, W. M., Jr., and White, W. A., 1991, Decline of submerged vegetation in the Galveston Bay system: chronology and relationship to physical processes: Journal of Coastal Research, v. 7, no. 4, p. 1125-1138.
- Pulich, W. M., Jr., White, W. A., Castiglione, M., and Zimmerman, R. J., 1991, Status of submerged vegetation in the Galveston Bay system, *in* Shipley, F. S., and Kiesling, R. W., eds., Proceedings, Galveston Bay characterization workshop, February 21-23: Galveston Bay National Estuary Program, GBNEP Publication-6, p. 127-132.
- Ratzlaff, K. W., 1980, Land-surface subsidence in the Texas coastal region: U.S. Geological Survey Open-File Report 80-969, 19 pp.
- Redfield, A. C., 1972, Development of a New England salt marsh: Ecological Monographs, v. 42, no. 2, p. 201-237.
- Reed, P. B., Jr., 1988, National list of plant species that occur in wetlands: 1988—Texas: U.S. Fish and Wildlife Service, St. Petersburg, Florida, variously paginated.
- Reid, W. M., 1973, Active faults in Houston, Texas: The University of Texas at Austin, Ph.D. dissertation, 122 pp.
- Riggio, R. R., Bomar, G. W., and Larkin, T. J., 1987, Texas drought: its recent history (1931-1985): Texas Water Commission, LP 87-04, 74 pp.
- Shaw, S. P., and Fredine, C. G., 1956, Wetlands of the United States, their extent and their value to waterfowl and other wildlife: U.S. Fish and Wildlife Service Circular 39, 47 pp.
- Shew, D. M., Baumann, R. H., Fritts, T. H., and Dunn, L. S., 1981, Texas barrier island region ecological characterization: environmental synthesis papers: U.S. Department of the Interior, U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C., FWS/OBS-81/32, 413 pp.

- Simpson, R. H., and Lawrence, M. B., 1971, Atlantic hurricane frequencies along the U.S. coastline: U.S. Department of Commerce, National Oceanic and Atmospheric Administration Technical Memorandum NWSSR-58, 14 pp.
- Swanson, R. L., and Thurlow, C. I., 1973, Recent subsidence rates along the Texas and Louisiana coasts as determined from tide measurements: *Journal of Geophysical Research*, v. 78, no. 5, p. 2665-2671.
- Texas Forest Service, 1963, Forest trees of Texas, how to know them: College Station, Texas A&M University Bulletin 20, 156 pp.
- Thomas, G. W. 1975, Texas plants—an ecological summary, *in* Gould, F. W., ed., Texas plants—a checklist and ecological summary: College Station, Texas Agricultural Experiment Station MP-585/Revised, p. 7-14.
- Thorntwaite, C. W., 1948, An approach toward a rational classification of climate: *Geographical Review*, v. 38, no. 1, p. 55-94.
- Tiner, R. W., Jr., 1984, Wetlands of the United States: current status and recent trends: U.S. Department of the Interior, U.S. Fish and Wildlife Service, 59 pp.
- Tremblay, T. A., 1992, A GIS study of cumulative wetland habitat change: the Virginia Point quadrangle, Galveston County, Texas: The University of Texas at Austin, Master's thesis, 106 pp.
- U.S. Army Corps of Engineers, 1956, Wave statistics for the Gulf of Mexico off Caplan, Texas: Beach Erosion Control Board Technical Memorandum No. 86, 51 pp.
- U.S. Department of Commerce, 1978, Tide current tables 1979, Atlantic coast of North America: National Oceanic and Atmospheric Administration, National Ocean Survey, 231 pp.
- U.S. Fish and Wildlife Service, 1983, Unpublished digital data of wetland maps of the Texas Coastal zone prepared from mid-1950's and 1979 aerial photographs: Office of Biological Services, U.S. Fish and Wildlife Service.
- Van Sicle, D., 1967, The Houston fault problem: Institute of Professional Geologists, Texas Section, proceedings of Third Annual Meeting, p. 9-31.
- Verbeek, E. R., and Clanton, U. S., 1981, Historically active faults in the Houston metropolitan area, Texas, *in* Etter, E. M, ed., Houston area environmental geology: surface faulting, ground subsidence, hazard liability: Houston Geological Society, p. 28-68.

- Weaver, P., and Sheets, M., 1962, Active faults, subsidence and foundation problems in the Houston, Texas, area, *in* *Geology of the Gulf Coast and Central Texas: Houston Geological Society Guidebook*, p. 254–265.
- Webb, J. W., 1983, Soil water salinity variations and their effects on *Spartina alterniflora*: *Contributions in Marine Science*, v. 26, p. 1–13.
- Wheeler, F. F., and others, 1976, Soil survey of Harris County, Texas: U.S. Department of Agriculture, Soil Conservation Service, 140 pp., 140 maps.
- White, W. A., and Calnan, T. R., 1990, Sedimentation and historical changes in fluvial-deltaic wetlands along the Texas Gulf Coast with emphasis on the Colorado and Trinity River deltas: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Texas Parks and Wildlife Department, 124 pp., 7 appendices.
- White, W. A., and Calnan, T. R., 1991, Submergence of vegetated wetlands in fluvial-deltaic areas, Texas Gulf Coast, *in* *Coastal Depositional Systems, Gulf of Mexico: Houston, Society of Economic Paleontologists and Mineralogists, Gulf Coast Section, 12th annual research conference, program with extended and illustrated abstracts*, p. 278–279.
- White, W. A., Calnan, T. R., Morton, R. A., Kimble, R. S., Littleton, T. G., McGowen, J. H., and Nance, H. S., 1987, Submerged lands of Texas, Beaumont–Port Arthur area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands: The University of Texas at Austin, Bureau Economic Geology Special Publication, 110 pp.
- White, W. A., Calnan, T. R., Morton, R. A., Kimble, R. S., Littleton, T. G., McGowen, J. H., Nance, H. S., and Schmedes, K. E., 1985, Submerged lands of Texas, Galveston–Houston area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands: The University of Texas at Austin, Bureau of Economic Geology Special Publication, 145 pp.
- White, W. A., and Paine, J. G., 1992, Wetland plant communities, Galveston Bay system: Galveston Bay National Estuary Program, GBNEP Publication–16, 124 pp.
- Winslow, A. G., and Doyel, W. W., 1954, Land-surface subsidence and its relation to the withdrawal of ground water in the Houston–Galveston region, Texas: *Economic Geology*, v. 49, no. 4, p. 413–422.
- Zimmerman, R. J., Minello, T. J., Klima, E. F., and Nance, J. M., 1991, Effects of accelerated sea-level rise on coastal secondary production, *in* Bolton, H. S., and Magoon, O. T., eds., *Coastal wetlands: American Society of Civil Engineers*, New York, p. 110–124.
- Zinn, J. A., and Copeland, C., 1982, Wetland management: Environment and Natural Resources Policy Division, Congressional Research Service, Library of Congress Serial No. 97-11, 149 pp.