3.3 Habitat

3.3.1 Assessment of Wetland Loss and Gain Projections

<u>Introduction</u>

Wetlands are tremendously important habitats to the Galveston Bay Estuary. Wetlands provide important nursery, shelter, and foraging areas for many species of fish and wildlife; stabilize bay sediments; improve water quality; reduce shoreline erosion; and alleviate coastal flooding. Two major types of wetlands are found in the Lower Galveston Bay watershed: palustrine and estuarine wetlands.

Estuarine wetlands are tidal wetlands with salinities greater than 0.5 parts per thousand (ppt). They exist adjacent to bay waters and consist of emergent vegetation (vascular plants rooted in wetland soils with leaves emerging above the water surface) and scrub/shrub vegetation (woody plants less than 5 meters (m) in height) (NOAA 2006). A third class of estuarine wetlands, estuarine forested wetlands, do not exist in the Galveston Bay Estuary. Estuarine wetlands are also called fringing marsh or tidal marsh and are regularly flooded by the bay's tides. Estuarine wetlands are composed of salt-tolerant species of grasses, predominantly (White 1993):

- *Spartina alterniflora*
- *Distichlis spicata*
- *Salicornia* spp.
- *Batis maritime*
- *Juncus roemerianus*
- *Scirpus maritimus*
- *Spartina patens*
- *Spartina spartinae*
- *Borrichia frutescens*

Palustrine wetlands are freshwater wetlands with salinities less than 0.5 ppt. They are found inland of the bay and consist of emergent vegetation (vascular plants rooted in wetland soils with leaves emerging above the water surface), scrub/shrub vegetation (woody plants less than 5 meters in height) and forests (woody plants greater than 5 m in height) (NOAA 2006). Palustrine wetlands are also referred to as "isolated wetlands" or "prairie pothole complexes"; and although they may not be directly adjacent to bay waters and tributaries, they provide ecosystem functions as essential to the health of the Galveston Bay Estuary as those provided by estuarine wetlands. Palustrine marshes are typically inundated by freshwater and are composed of plant species that can tolerate both wet and dry conditions, predominantly (White 1993):

- *Scirpus californicus*
- *Typha* spp.
- *Cyperus articulatus*
- *Spartina patens*
- *Scirpus americanus*
- *Polygonum hydropiperoides*
- *Bacopa monnieri*
- *Phragmites australis*
- *Eleocharis* spp.
- *Zizaniopsis miliacea*

With the advent of geographic information systems (GIS) and the continuing development of geospatial analytical methods, numerous studies have sought to estimate the areal coverage of Galveston Bay's estuarine and palustrine wetlands (Jacob 2005; Pulich 1996; USFWS 1992; Webb 2005; White 1993). While all offer varying quantifications of wetland acreage, they have formed the basis of one common conclusion: wetland habitats have been lost at a tremendous rate in the Lower Galveston Bay watershed since the 1950s due to:

- conversion of habitat for industrial, agricultural, urban, and suburban land uses,
- subsidence and relative sea level rise,
- channel dredging, and
- damage caused by major storms including hurricanes.

In 2005 the GBEP funded an analysis of palustrine wetland loss in the Lower Galveston Bay Watershed (Jacob, 2005). Jacob found that at least 3.1 percent of palustrine wetlands in the Lower Galveston Bay Watershed were lost to development between the years 1992 and 2002. Most of those losses occurred in Harris County which lost 13 percent of its freshwater wetlands. More than half of the losses in Harris County occurred in a two year period (between 2000 and 2002). With suburban development increasing in previously rural counties such as Brazoria, Fort Bend, and Liberty, additional losses of palustrine wetlands are projected for the coming years.

In an effort to slow the loss of wetland habitats, the *Galveston Bay Plan* (*The Plan*) calls for the creation or restoration of 15,000 acres of wetlands by the year 2016; including 1,400 acres of submerged aquatic vegetation, 5,000 acres of palustrine wetlands, and 8,600 acres of estuarine emergent wetlands (GBNEP 1994). The Galveston Bay Status and Trends Project was given the task of determining if GBEP will reach its programmatic wetland restoration and creation goals by assessing and projecting wetland losses and gains to the year 2016.

Methods to Assess Trends in Wetland Habitat

Geospatial data were obtained from the National Oceanic and Atmospheric Administration (NOAA) Coastal Change Analysis Program (C-CAP). The C-CAP land cover classification is based on Landsat Thematic Mapper satellite imagery. The data have a spatial resolution of 30 m and a target accuracy of 85%. C-CAP data are mapped at 1:100,000 scale with 22 standard classes representing major landscape types. C-CAP classification is supported by ground truthing and the use of supplementary data such as U.S. Geological Survey (USGS) maps, Topologically Integrated Geographic Encoding and Referencing system (TIGER) road data, and National Wetland Inventory (NWI) data. In an effort to be consistent with wetland classifications prepared by other agencies, the wetland data included in the C-CAP Coastal Land Cover Classification System are based on the Cowardin classification (Cowardin 1979). Detailed information describing the C-CAP methodology can be found online at http://www.csc.noaa.gov/crs/lca/pdf/protocol.pdf.

NOAA C-CAP inventoried and described the change in land cover along the Texas-Louisiana coast over a five year period, 1996 to 2001. For the purposes of the Status and Trends Project, only the wetland classification data for the Lower Galveston Bay watershed (21 subwatersheds and five counties) were analyzed. Five C-CAP wetland classes analyzed by the Status and Trends Project included: Estuarine Emergent Wetland, Estuarine Scrub/Shrub Wetland, Palustrine Emergent Wetland, Palustrine Forested Wetland, and Palustrine Scrub/Shrub Wetland.

Three wetland classes were not included in the wetland change analysis. Estuarine Forested Wetlands (e.g. mangroves) do not exist in the Galveston Bay Estuary. Also not analyzed were the Estuarine Aquatic Bed and Palustrine Aquatic Bed classes. The aquatic bed classes do not allow one to differentiate between submerged aquatic vegetation (seagrass) and other aquatic vascular plants such as invasive water hyacinth (*Eichhornia crassipes*) and Salvinia (*Salvinia molesta*).

Wetland acreages from previous wetland assessment studies and land cover classifications (Jacob 2005; Pulich 1996; USFWS 1992; Webb 2005; White 1993) cannot be directly compared to the results of Galveston Bay Status and Trends Project's C-CAP data analyses. The land cover classifications use different remote sensing imagery as baseline data sets (e.g. aerial photos versus satellite imagery), assess geographic areas of varying size, and use slightly differing habitat classification systems.

In addition to analyzing data from NOAA C-CAP, the Status and Trends Project collected and assessed wetland permit and mitigation data from the U.S. Army Corps of Engineers (COE) Galveston District. COE permit and mitigation data were difficult to obtain and the quality of acquired data proved problematic. It is impossible to glean an accurate number of wetland acres altered by Section 10/404 permit and mitigation activities in the Lower Galveston Bay watershed at this time. However, COE permit data obtained from Dr. Samuel Brody at Texas A&M University do allow for an assessment of trends in permitted activities over a twelve year period (1992-2003) as well as an assessment of the locations of permitted activities. It is the hope of the Status and Trends Project that improvements in the COE's data management system will allow for a quantification of wetland alteration and mitigation in the near future.

Status of Wetland Habitat in the Subwatersheds of Galveston Bay

Five C-CAP wetland classes were analyzed to detect changes in acreage during the period 1996 to 2001. The area of land analyzed (a total land area of 2,742,911 acres) included the 21 subwatersheds of the Lower Galveston Bay watershed (see map in Figure 3.3.1). The total acreage of estuarine and palustrine wetlands in this area in 2001 was estimated to be 729,710 acres or 27 percent of the total land area.

Figure 3.3.1. Map depicting geographic differences between the counties and subwatersheds existing in the Lower Galveston Bay watershed. These geographic differences account for the acreage difference in the wetland change analysis at the county and subwatershed scales.

As seen in Table 3.3.1, net loss of wetlands (loss of wetlands offset by gains) totaled 5,656 acres in the 21 subwatersheds surrounding Galveston Bay during the five year period, 1996 to 2001. All losses occurred in the palustrine wetland classes of palustrine scrub/shrub wetlands (3,930 acres lost) and palustrine emergent wetlands (1,899 acres lost). Acreage of estuarine scrub/shrub wetlands showed no change in the 1996 to 2001 period. Slight gains in estuarine emergent and palustrine forested wetlands of 50 and 122 acres, respectively, were not considered significant.

Table 3.3.1. Change in acreage of five wetland classes in 21 subwatersheds of the Lower Galveston Bay watershed, 1996 to 2001. Original data source: NOAA Coastal Change Analysis Program.

Wetland Class	Acres in 1996	Acres in 2001	Acreage Change 1996-2001
Estuarine Emergent Wetland	124,333	124,383	50
Estuarine Scrub/Shrub Wetland	244	244	0
Palustrine Emergent Wetland	135,448	133,549	-1,899
Palustrine Forested Wetland	418,469	418,591	122
Palustrine Scrub/Shrub Wetland	56,873	52,943	-3,930
TOTAL	**735,366**	**729,710**	**-5,656**

When the data were analyzed geographically by subwatershed, it was determined that the areas with the largest acreages of remaining wetlands in 2001 were the Trinity River (310,499 acres), East Bay (85,318 acres), West Bay (77,917 acres), and Austin-Bastrop Bayou (70,960 acres) subwatersheds (Table 3.3.2). During the period 1996 to 2001, the greatest wetland losses occurred in the Trinity River (-1,797 acres), Trinity Bay (-1,035 acres), and Clear Creek (-852 acres) subwatersheds. Of those areas, Clear Creek presents the most alarming losses, given that the Clear Creek subwatershed had fewer wetlands to begin with in 1996 relative to other Galveston Bay subwatersheds. Also of note are the Brays Bayou and White Oak Bayou subwatersheds which saw decreases in wetland acreage of 31 percent and 19 percent respectively.

Table 3.3.2. Change in acreage of wetlands in 21 watersheds of the Lower Galveston Bay watershed, 1996 to 2001. Original data source: NOAA Coastal Change Analysis Program.

Subwatershed	Acres in 1996	Acres in 2001	Acreage Change 1996-2001
Addicks Reservoir	7,554	7,504	-50
Armand Bayou	6,702	6,574	-128
Austin-Bastrop Bayou	70,981	70,960	-21
Barker Reservoir	10,887	10,924	37
Brays Bayou	521	362	-159
Buffalo Bayou	455	427	-28
Cedar Bayou	24,554	24,275	-278
Chocolate Bayou	14,356	14,151	-206
Clear Creek	10,131	9,279	-852
Dickinson Bayou	7,553	7,304	-249
East Bay	85,319	85,318	-2
Greens Bayou	12,353	12,059	-294
Houston Ship Channel	6,020	5,756	-263
North Bay	2,892	2,872	-19
San Jacinto River	9,933	9,965	32
Sims Bayou	1,621	1,550	-72
South Bay	14,059	14,031	-28
Trinity Bay	58,582	57,546	-1,035
Trinity River	312,296	310,499	-1,797
West Bay	78,057	77,917	-140
White Oak Bayou	541	437	-104
TOTAL	**735,366**	**729,710**	**-5,656**

Status of Wetland Habitat in Five Counties of the Lower Galveston Bay Watershed

The analysis of the C-CAP data was then expanded to analyze the change in wetlands in the five county region in and around Galveston Bay (Brazoria, Chambers, Galveston, Harris, and Liberty counties) during the same period, 1996 to 2001. The area of land within the five counties (3,438,890 acres) includes the 21 subwatersheds and extends farther inland. The change in area presents a slightly different view of wetland alterations as seen above in the section on subwatersheds.

The total acreage of wetlands in the five counties was estimated to be 962,340 acres or 28 percent of the total county land area in 2001. When compared to losses in the 21 subwatersheds, net loss of wetlands in the five county area nearly doubled to 10,440 acres during the same 1996 to 2001 period (see Table 3.3.3). This is due to the fact that additional losses in wetlands occurred farther inland outside of the subwatershed boundaries, but still within county boundaries.

As in the subwatershed areas, all losses occurred in palustrine wetlands, specifically palustrine forested wetlands (-4,878 acres), palustrine scrub/shrub wetlands (-3,600 acres), and palustrine emergent wetlands (-1,996 acres). Slight gains in estuarine emergent and estuarine scrub/shrub of 34 acres and 1 acre, respectively, are not considered significant.

Table 3.3.3. Change in acreage of five wetland classes in five counties of the Lower Galveston Bay watershed, 1996 to 2001. Original data source: NOAA Coastal Change Analysis Program.

Wetland Class	Acres in 1996	Acres in 2001	Acreage Change 1996-2001
Estuarine Emergent Wetland	163,029	163,063	34
Estuarine Scrub/Shrub Wetland	230	231	1
Palustrine Emergent Wetland	169,746	167,750	-1,996
Palustrine Forested Wetland	564,714	559,836	-4,878
Palustrine Scrub/Shrub Wetland	75,061	71,460	-3,600
TOTAL	**972,780**	**962,340**	**-10,440**

When the C-CAP wetland data were analyzed by county, it was determined that the areas with the largest acreages of remaining wetlands in 2001 were Brazoria County (343,635 acres) and Liberty County (300,326 acres) (Table 3.3.4). During the period 1996 to 2001, the greatest wetland losses occurred in Liberty County (7,043 acres lost) and Harris County (1,991 acres lost).

Table 3.3.4. Change in acreage of wetlands in 5 counties of the Lower Galveston Bay watershed, 1996 to 2001. Original data source: NOAA Coastal Change Analysis Program.

County	Acres in 1996	Acres in 2001	Acreage Change 1996-2001
Brazoria	344,187	343,635	-552
Chambers	137,429	137,380	-48
Galveston	80,873	80,068	-805
Harris	102,923	100,932	-1,991
Liberty	307,369	300,326	-7,043
TOTAL	**972,780**	**962,340**	**-10,440**

Projected Change in Wetland Habitat 1996-2016

Changes in wetland acreage over the 1996 to 2001 time period (Tables 3.3.1 through 3.3.4) were used to project changes in wetlands in the Lower Galveston Bay watershed at five-year intervals to the year 2016 (see Table 3.3.5). Three five-year intervals (2006, 2011, and 2016) were calculated by summing the 1996 to 2001 losses/gains with acreage totals of the previous time interval. For example, the 2006 projection was calculated by summing the 1996 to 2001 change (losses and gains) with the 2001 acreage estimate. Projections are reported below at both the subwatershed and county levels by wetland class and geographical subdivision.

This very basic model assumes a constant rate of loss. The model is not meant to give an exact estimate of projected wetland change but is meant to give the reader an idea of the changes that can be expected if the 1996 to 2001 rate of wetland alteration activities continues and all other variables remain equal. Many variables such as changes in economic markets and development patterns, severity of storms, and changes in regulatory requirements influence the rate of wetland alteration. For example the effects of the 2001 US Supreme Court ruling known as SWANCC will not be seen in the 1996 to 2001 C-CAP change analysis. Rather, changes in the development of palustrine wetlands that resulted from the SWANCC ruling will be evidenced in the 2001 to 2006 C-CAP change analysis when and if it is completed by NOAA. For this reason, the projected changes in palustrine wetlands may be a conservative estimate.

Projected Change in Subwatersheds of the Lower Galveston Bay Watershed

As seen in Table 3.3.5, projected net loss of wetlands at the subwatershed level is expected to total 22,625 acres by the year 2016 with 69% (15,721 acres) of that loss expected to occur in palustrine scrub/shrub wetlands and 34% (7,596 acres) of the loss expected to occur in palustrine emergent wetlands. Little change to slight gains are expected in palustrine forested, estuarine emergent, and estuarine scrub/shrub wetland classes.

Table 3.3.5. Projected change in acreage of five wetland classes in 21 subwatersheds of the Lower Galveston Bay watershed, 1996 to 2016. Original data source: NOAA Coastal Change Analysis Program.

Wetland Class	C-CAP 1996 (Acres)	C-CAP 2001 (Acres)	Projected 2006 (Acres)	Projected 2011 (Acres)	Projected 2016 (Acres)	Projected Change 1996-2016 (Acres)
Estuarine Emergent Wetland	124,333	124,383	124,434	124,484	124,535	202
Estuarine Scrub/Shrub Wetland	244	244	244	244	244	1
Palustrine Emergent Wetland	135,448	133,549	131,650	129,751	127,852	-7,596
Palustrine Forested Wetland	418,469	418,591	418,713	418,836	418,958	489
Palustrine Scrub/Shrub Wetland	56,873	52,943	49,013	45,083	41,152	-15,721
TOTAL	**735,366**	**729,710**	**724,054**	**718,398**	**712,742**	**-22,625**

When the same projections are viewed geographically by subwatershed (Table 3.3.6), the greatest losses are projected to occur in the palustrine wetlands of the Trinity River (7,188 acres), Trinity Bay (4,142 acres), and Clear Creek (3,408 acres) watersheds. Houston's urban bayou watersheds including Brays, White Oak, Buffalo, and Sims will have little or no wetlands remaining by the year 2016 given the current rate of wetland loss. Note that the total net loss figures in Tables 3.3.5 and 3.3.6 differ by 117 acres. This is due to the fact that Brays Bayou losses in Table 3.3.6 are stopped at zero.

Table 3.3.6. Projected change in acreage of wetlands in 21 watersheds of the Lower Galveston Bay watershed,
1996 to 2016. Original data source: NOAA Coastal Change Analysis Program.

Subwatershed	C-CAP 1996 (Acres)	C-CAP 2001 (Acres)	Projected 2006 (Acres)	Projected 2011 (Acres)	Projected 2016 (Acres)	Projected Change 1996-2016 (Acres)
Addicks Reservoir	7,554	7,504	7,454	7,404	7,355	-199
Armand Bayou	6,702	6,574	6,446	6,317	6,189	-513
Austin-Bastrop Bayou	70,981	70,960	70,939	70,918	70,896	-85
Barker Reservoir	10,887	10,924	10,961	10,997	11,034	147
Brays Bayou	521	362	202	43	0	-521
Buffalo Bayou	455	427	399	371	344	-111
Cedar Bayou	24,554	24,275	23,997	23,718	23,440	-1,114
Chocolate Bayou	14,356	14,151	13,945	13,739	13,533	-823
Clear Creek	10,131	9,279	8,427	7,575	6,723	-3,408
Dickinson Bayou	7,553	7,304	7,055	6,807	6,558	-995
East Bay	85,319	85,318	85,316	85,314	85,312	-7
Greens Bayou	12,353	12,059	11,764	11,470	11,175	-1,178
Houston Ship Channel	6,020	5,756	5,493	5,230	4,967	-1,052
North Bay	2,892	2,872	2,853	2,834	2,814	-77
San Jacinto River	9,933	9,965	9,998	10,030	10,062	130
Sims Bayou	1,621	1,550	1,478	1,406	1,335	-286
South Bay	14,059	14,031	14,003	13,976	13,948	-111
Trinity Bay	58,582	57,546	56,511	55,475	54,440	-4,142
Trinity River	312,296	310,499	308,702	306,905	305,108	-7,188
West Bay	78,057	77,917	77,778	77,638	77,498	-559
White Oak Bayou	541	437	333	229	125	-415
TOTAL	**735,366**	**729,710**	**724,054**	**718,398**	**712,858**	**-22,508**

Projected Change in Counties of the Lower Galveston Bay Watershed

When calculated at the county-level, the projected losses in wetlands are nearly double those calculated at the subwatershed level. This is due to the fact that the area of land included within county boundaries is larger than the area of land included within the subwatershed boundaries. Additional changes in wetlands occurred farther inland outside of the subwatershed boundaries, but still within county boundaries. In addition to increasing the acreage of projected wetland loss, the extension of the data to the county boundaries also changes the nature of the wetland loss.

As seen in Table 3.3.7, projected net loss of wetlands at the subwatershed level is expected to total 41,757 acres by the year 2016 with 47 percent (19,512 acres) of that loss expected to occur in palustrine forested wetlands, 34 percent (14,400 acres) of the loss expected to occur in palustrine scrub/shrub wetlands, and 19 percent of the loss (7,984 acres) expected to occur in palustrine emergent wetlands. Little change or a slight gain is expected to occur in estuarine emergent and estuarine scrub/shrub wetland classes.

Table 3.3.7. Projected change in acreage of five wetland classes in five counties of the Lower Galveston Bay watershed, 1996 to 2016. Original data source: NOAA Coastal Change Analysis Program.

Wetland Class	C-CAP 1996 (Acres)	C-CAP 2001 (Acres)	Projected 2006 (Acres)	Projected 2011 (Acres)	Projected 2016 (Acres)	Projected Change 1996-2016 (Acres)
Estuarine Emergent Wetland	163,029	163,063	163,097	163,131	163,165	136
Estuarine Scrub/Shrub Wetland	230	231	232	233	234	4
Palustrine Emergent Wetland	169,746	167,750	165,754	163,758	161,762	-7,984
Palustrine Forested Wetland	564,714	559,836	554,958	550,080	545,202	-19,512
Palustrine Scrub/Shrub Wetland	75,061	71,460	67,860	64,260	60,660	-14,400
TOTAL	**972,780**	**962,340**	**951,901**	**941,462**	**931,023**	**-41,757**

When calculated geographically by county, 67 percent (28,172 acres) of losses are expected to occur in the palustrine wetlands of Liberty County and 19 percent (7,964 acres) palustrine wetlands are projected to be lost in Harris County.

Table 3.3.8. Projected change in acreage of wetlands in 5 counties of the Lower Galveston Bay watershed, 1996 to 2016. Original data source: NOAA Coastal Change Analysis Program.

County	C-CAP 1996 (Acres)	C-CAP 2001 (Acres)	Projected 2006 (Acres)	Projected 2011 (Acres)	Projected 2016 (Acres)	Projected Change 1996-2016 (Acres)
Brazoria	344,187	343,635	343,083	342,531	341,979	-2,208
Chambers	137,429	137,380	137,332	137,284	137,236	-192
Galveston	80,873	80,068	79,263	78,458	77,653	-3,220
Harris	102,923	100,932	98,941	96,950	94,959	-7,964
Liberty	307,369	300,326	293,283	286,240	279,197	-28,172
TOTAL	**972,780**	**962,340**	**951,901**	**941,462**	**931,023**	**-41,757**

Trends in Wetland Permits

The Status and Trends Project originally attempted to obtain the wetland permit data directly from the Corps of Engineers Galveston District. After a written request for electronic data from the COE Regulatory Analysis and Management System (RAMS) was denied, the Status and Trends Project attempted to gather the permit data directly from the COE permit files located at the Galveston, Texas COE office. The data were gathered by Ms. Allison Pollock over the summer of 2004. During that time, hard copies of RAMS data reports were also obtained from the COE by Ms. Pollock. The reports were digitized and imported into a database to enable statistical and geospatial analysis.

In the end, the permit file and RAMS data obtained directly from the COE proved to be problematic and could not be used due to data quality issues introduced by the source agency. Very often geospatial information describing the location of a permit was not included in the COE file or was incorrect. Quantitative data describing acreage of land impacted by the permit was often not included or was entered into a textual data field such as project description. Data describing acreage of the required mitigation activity was absent. Data within fields were not in standardized formats (e.g. project names and description of approved work sometimes contained conflicting information). These combined data quality issues made a quantitative analysis of the permit data acquired from the COE impossible to complete.

To complete the analysis, the Status and Trends Project obtained a copy of the COE RAMS data from Dr. Samuel Brody of Texas A&M University, Department of Landscape Architecture and Urban Planning. Dr. Brody and his team of researchers obtained this version of the COE RAMS data directly for the COE Galveston, Texas office. The database includes permit number, applicant, issue date, latitude and longitude of the permitted activity, and permit type. The Status and Trends Project inserted additional geographic information (subwatershed and county names) to facilitate data analysis. Acreage of permitted activities, acreage of mitigation activities, and data describing monitoring of permit and mitigation activities is not included in this data set.

To facilitate analysis, duplicate permit records were removed as were permit records with incorrect or unknown latitudes and longitudes. A summary of the data finds that a total of 3,067 permits were issued by the COE during the years 1992-2003 in the five counties (Brazoria, Chambers, Galveston, Harris, and Liberty) surrounding Galveston Bay. During that time, the number of wetland permits issued annually by the Corps of Engineers exhibited an increasing trend (R^2=0.38) (Figure 3.3.2).

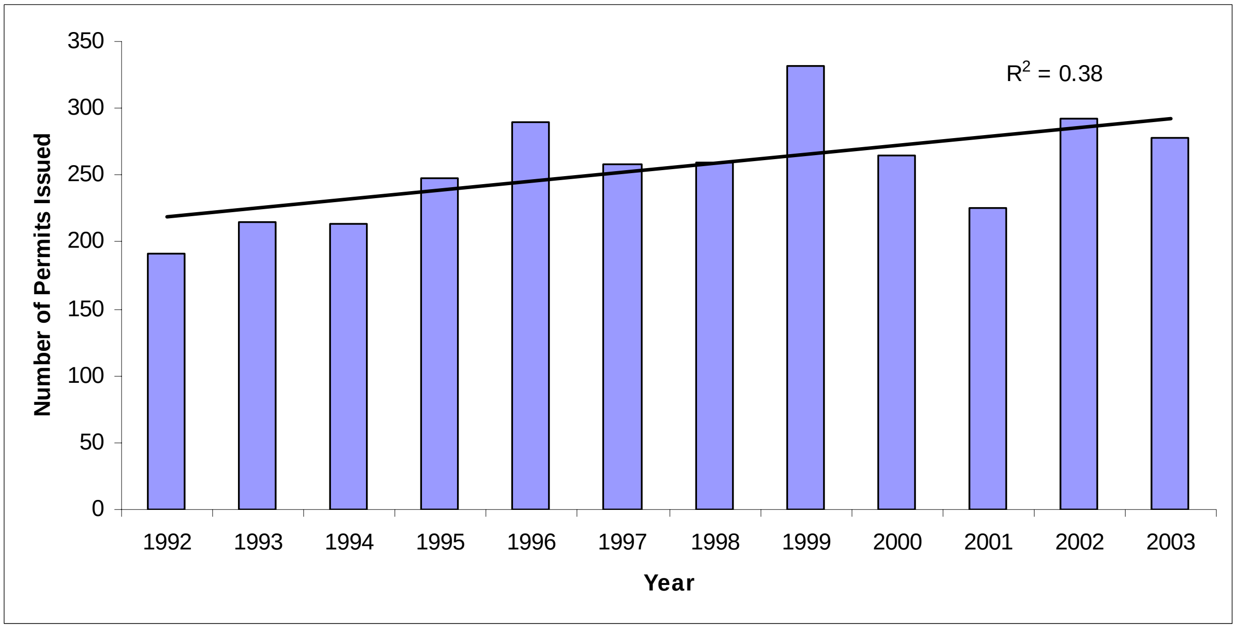

Figure 3.3.2. Number of approved COE Section 10/404 wetland permits issued in the five counties surrounding Galveston Bay during the period 1992-2003. Data source: US Army Corps of Engineers Regulatory Analysis and Management System (RAMS) data obtained from Dr. Samuel Brody of Texas A&M University, Department of Landscape Architecture and Urban Planning.

As seen in Figure 3.3.3, of the five counties surrounding Galveston Bay, Harris County and Galveston County had the greatest total number of COE-approved Section 10/404 wetland permits with 1,274 permits and 828 permits, respectively during the 1992-2003 time period. Alternatively, Liberty County and Chambers County had the least number of COE-approved 10/404 wetland permits with 91 permits and 154 permits, respectively during the 1992-2003 time period.

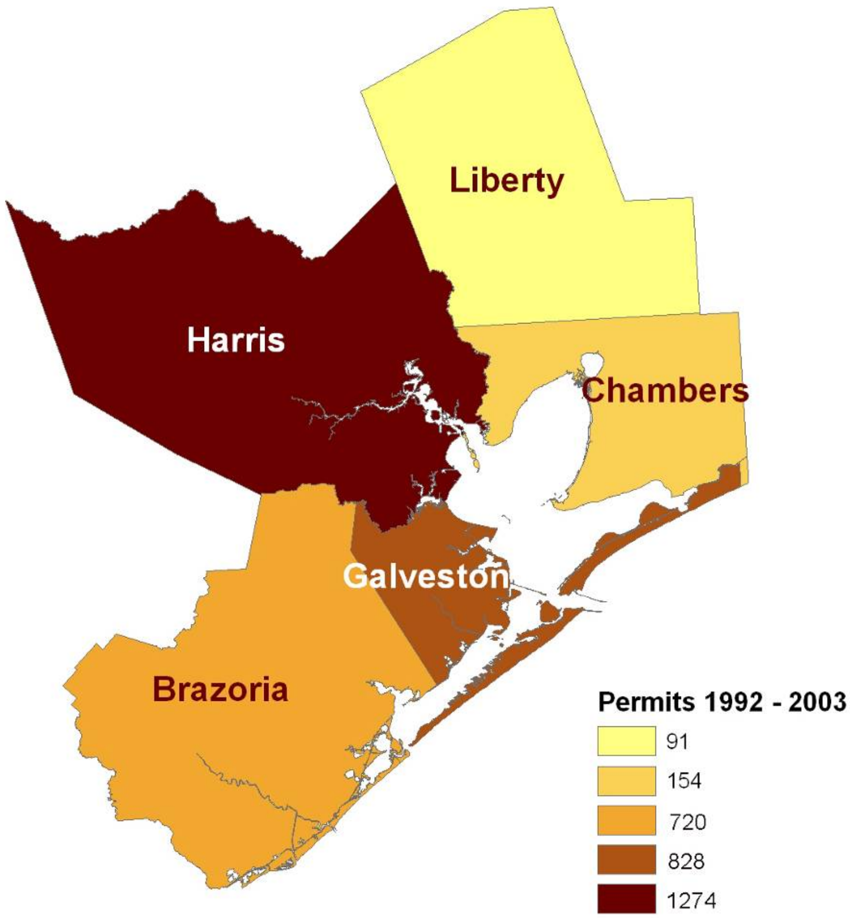

Figure 3.3.3. Number of wetland permits issued by the US Army Corps of Engineers Galveston District in the five counties surrounding Galveston Bay during the period 1992-2003. Data source: US Army Corps of Engineers Regulatory Analysis and Management System (RAMS) data obtained from Dr. Samuel Brody of Texas A&M University, Department of Landscape Architecture and Urban Planning.

Of the five counties surrounding Galveston Bay, Chambers County has the greatest increasing trend (R^2=0.70) in the number of Section 10/404 wetland permits approved annually for the period 1992-2003. The remaining four counties (Brazoria, Galveston, Harris, and Liberty) exhibited no significant trends.

Looking at a slightly different spatial scale, a total of 2,238 permits were issued by the COE during the years 1992-2003 in the 21 subwatersheds in the Lower Galveston Bay watershed. During that time, the number of wetland permits issued annually by the Corps of Engineers exhibited an increasing trend (R^2=0.38).

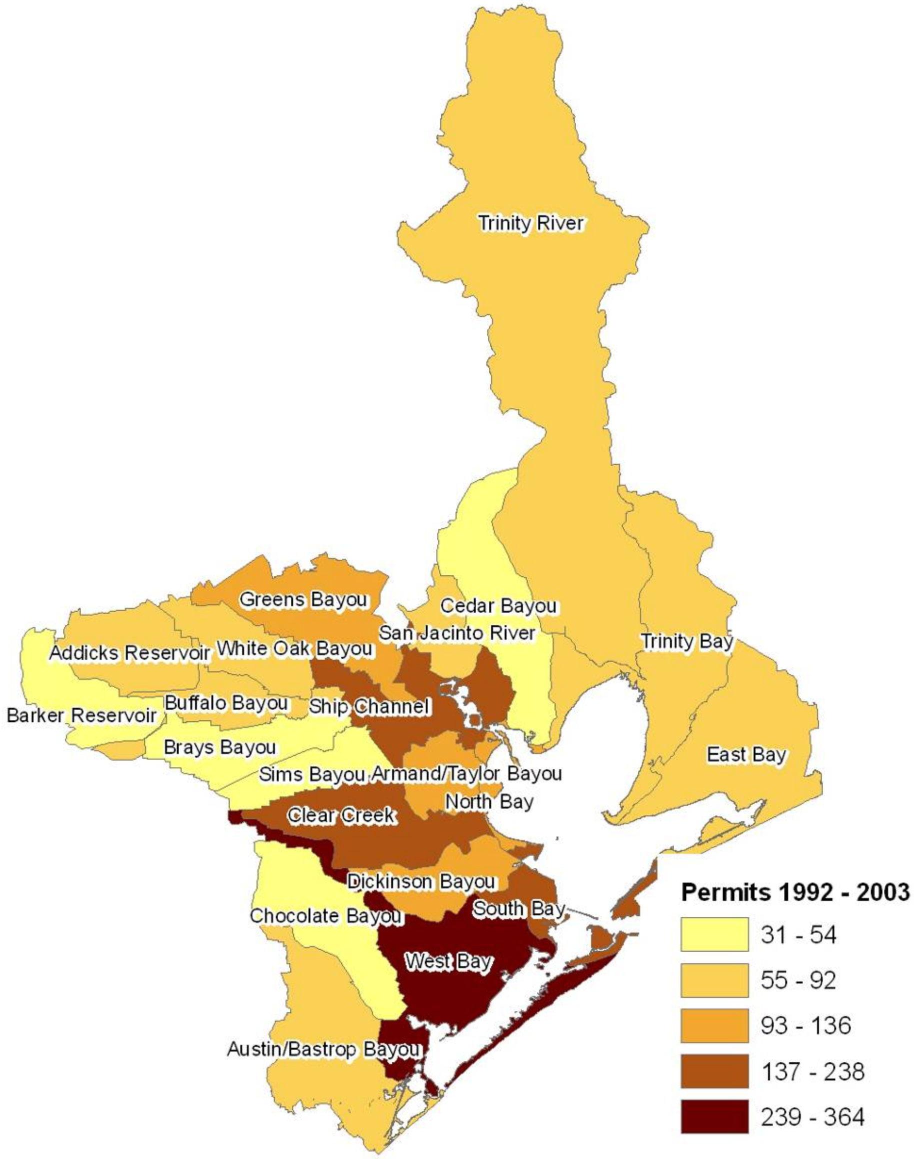

Figure 3.3.4. Number of wetland permits issued by the US Army Corps of Engineers Galveston District in 21 subwatersheds surrounding Galveston Bay during the period 1992-2003. Data source: US Army Corps of Engineers Regulatory Analysis and Management System (RAMS) data obtained from Dr. Samuel Brody of Texas A&M University, Department of Landscape Architecture and Urban Planning.

Of the 21 subwatersheds, four exhibited increasing trends in wetland permits issued annually during the period 1992-2003: Addicks Reservoir (R^2=0.50), East Bay (R^2=0.46), South Bay (R^2=0.52), and Trinity Bay (R^2=0.44). All other subwatersheds exhibited no trends.

Seven types of COE-approved Section 10/404 wetland permits were found in the COE RAMS data: 1) After the Fact - Nationwide Permit, 2) After the Fact - Individual Permit, 3) After the Fact - Letter of Permission, 4) Letter of Permission, 5) Individual Permit, 6) General Permit, and 7) Nationwide Permit. Of the 3,067 permits issued in 1992-2003 in the five counties, 1,825 were Nationwide Permits (60% of all permits issued), 571 (19% of the total) were General Permits, and 349 (11% of the total) were Individual Permits. The other four types made up the remaining 10%.

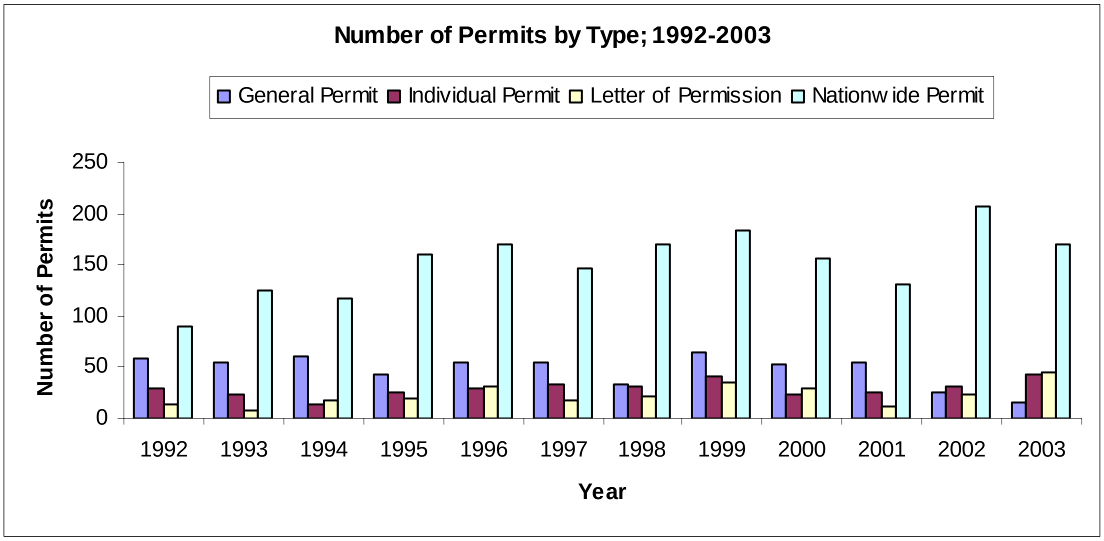

Figure 3.3.5. Number of wetland permits issued by the US Army Corps of Engineers Galveston District by permit type during the period 1992-2003. Data source: US Army Corps of Engineers Regulatory Analysis and Management System (RAMS) data obtained from Dr. Samuel Brody of Texas A&M University, Department of Landscape Architecture and Urban Planning.

48 After-the-Fact permits were issued during the 1992-2003 period, 1.6% of the total permits issued. Of the four types of "Before the Fact" permits (Letter of Permission, Individual Permit, General Permit, and Nationwide Permit), a decreasing trend was seen over the 1992-2003 time period for the annual issuance of General Permits (R^2=0.34; $p<0.05$). Alternately, increasing trends were observed for Letters of Permission (R^2=0.36; $p<0.05$) and Nationwide Permits (R^2=0.47; $p<0.05$). No trend was observed for the annual issuance of Individual Permits.

3.3.2 Habitat Fragmentation Analysis

The impact of habitat fragmentation on the abundance of organisms and the extinction probability of species dependent on the habitat type has been studied extensively. The underlying principles of the effect are accepted and explained in textbooks on ecology and conservation biology (Meffe 1997; Smith 2002). The negative impact of fragmentation is an expression of several factors. First, all organisms require a sufficient area of habitat with certain resources to survive. If the patch of habitat in which an organism resides is too small and it can not access additional resources, it will die. Second, the probability of mortality is associated with factors beyond resources, such as predation and disease. As habitat patches shrink, there is more exposure to habitat edges where predation is often higher and there is more vulnerability associated with movement from one patch to another. Third, there is the problem of demographics in shrinking patches. As patch size shrinks, so does population. This could result in a reduced likelihood of encountering a suitable mate for reproduction. These responses differ among species. The community of species dependent on a particular habitat or patch type will possess a variety of patch size requirements. Some smaller species, e.g. insects, may be resistant to the same fragmentation that will result in disappearance of large mammalian species.

Humans are responsible for many landscape changes that result in habitat fragmentation. The most dramatic are those long linear structures that traverse large areas, i.e. highways, power lines, and pipelines. Agricultural land use produces patches of habitat differentiated into pasture land, crop land, and managed tree plantations. Even the typical suburban yard is divided into patches of lawn and flower bed, and the yards are fragmented by driveways and streets.

Methodology

It is possible to classify pixels in remote sensing images according to their habitat or land cover type. Digital orthoquad photos from aerial images of the counties in the GBEP region (Brazoria, Chambers, Galveston, Harris and Liberty) were classified into nine classes: grassland, woody land, woody wetlands, non-woody wetlands, low intensity development, high intensity development, cultivated, bare transitional land, and open water by the Houston –Galveston Area Council (H-GAC). In our analysis, open water is excluded from the landscape and not considered. Developed, cultivated, and transitional land is included but not classified as a habitat type. Woody and non-woody wetlands are combined into a single wetland category. Woody land and grassland are maintained as distinct classes, but we will only discuss the fragmentation of woody land and wetlands because grasslands includes lawns and golf courses.

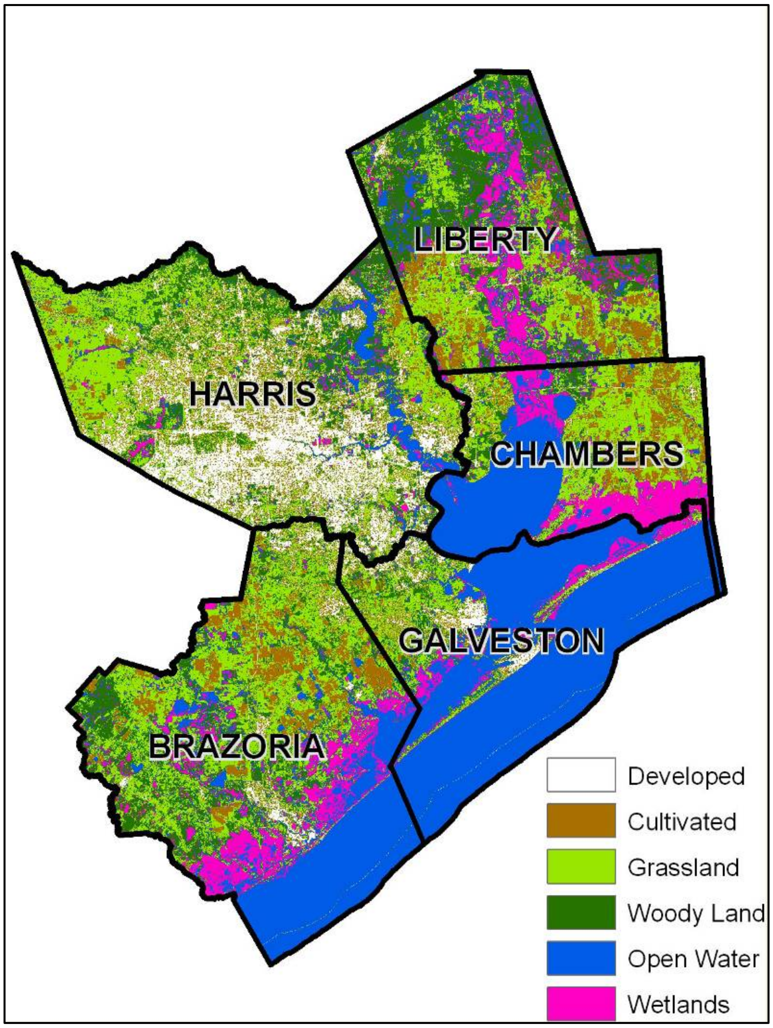

Figure 3.3.6. Classified image of the five counties using the modified classification scheme adopted for this study. Data Source: Houston –Galveston Area Council (H-GAC).

The analysis was done at the county and sub watershed level using a public domain program called *FRAGSTATS v. 3*. The software contains algorithms that calculate a variety of measures useful in assessing fragmentation. There is no standard method to summarize fragmentation. We developed a single measure based on statistics calculated by the software that focuses primarily on the size and distribution of the habitat patches. The effect of patch shape and edge amounts in a given area is not assessed. Edge effects are quite species specific. This is a general analysis of the extent of fragmentation in the Galveston Bay watershed and not a study of its effect on species.

The index of fragmentation (F) developed by the Status and Trends Project is:

$$\frac{(\text{normalized landscape shape index}) * (\text{patch density}) * (\text{mean distance to nearest neighbor}) * 10}{[\text{square root(mean patch area)}] * 10{,}000}$$

The normalized landscape shape index (NLSI) is a measure of shape complexity for which a square equals zero and a checkerboard equals 0.5. This measure has no units. Patch density is measured as patches of that classification per 100 hectares. Mean distance to nearest neighbor is based on the distances between patches of the same type and is measured in meters. Mean patch area is measured in hectares. The numerator is multiplied by 10 to reduce the effect of NLSI being between 0 and 0.5 on the scale of the index. The denominator is multiplied by 10,000 to convert hectares into square meters. The index (F) is a measure with no units and ranges from 0 to a maximum of less than five. The index can be considered as an indication of an idealized, even distribution of a number of same-sized patches over a ten hectare area. The larger the index, the greater is the number of patches of smaller size and farther apart.

The fragmentation analysis is based on a set of images from 2002 and does not include any evaluation of change over time. The number of habitat patches and their size is related to the distribution of habitats prior to human settlement and development. Thus while Buffalo Bayou may yield the highest fragmentation index for wetland habitat, it does not necessarily follow that human activity is completely responsible for the fragmented nature of that habitat in that watershed. The same analysis will need to be repeated with past or future images to determine the impact of human activity on the fragmentation of habitat.

Results

Wetlands by County

There are 209,771 hectares of land in the five counties classified as wetlands by H-GAC (a hectare is approximately 2.5 acres.) This amounts to 12.2% of the landscape with the exclusion of open water. The classification system identified 72,654 wetland patches in the area. This should be treated as an approximation because it is not possible to ground truth this classification to any great degree. The average size of these wetland patches is estimated to be 2.89 hectares. More than half are less than one hectare, but the maximum size is estimated to be more than 20,000 hectares.

Summation of the fragmentation index for wetlands by county shows that Harris County is far more fragmented than the other counties. F for wetlands is Harris = 0.312, Galveston = 0.038, Brazoria = 0.037, Liberty 0.036 and Chambers 0.010. Figure 3.3.6 shows a map of the county-level wetland fragmentation indices.

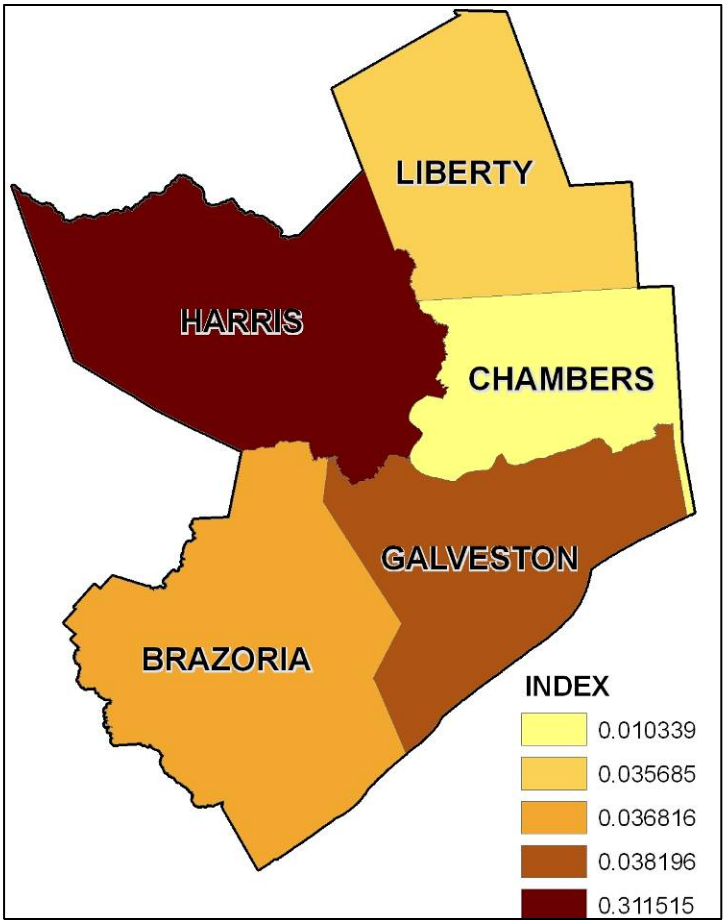

Figure 3.3.7. County-level wetland fragmentation of the Lower Galveston Bay watershed. The index (*F*) is a measure with no units and ranges from 0 to a maximum of less than five. The index can be considered as an indication of an idealized, even distribution of a number of same-sized patches over a ten hectare area.

Woody Land by County

According to this classification, there are 319,361 hectares of woody land in the five counties of the Lower Galveston Bay watershed, or 18.6% of the total landscape. The woody lands are fragmented into an estimated 102,648 patches with an average size of 3.1 hectares. The mean patch area is 3.1 hectares, but the largest patch is estimated to be over 48,000 hectares of continuous forest.

Calculation of a fragmentation index (*F*) for woody land by county again shows Harris County to be more fragmented than the others. This is obviously the result of Harris County being the location of Houston, the largest urban development in the region. The index values are shown in Figure 3.3.7, which illustrates the change in fragmentation among counties.

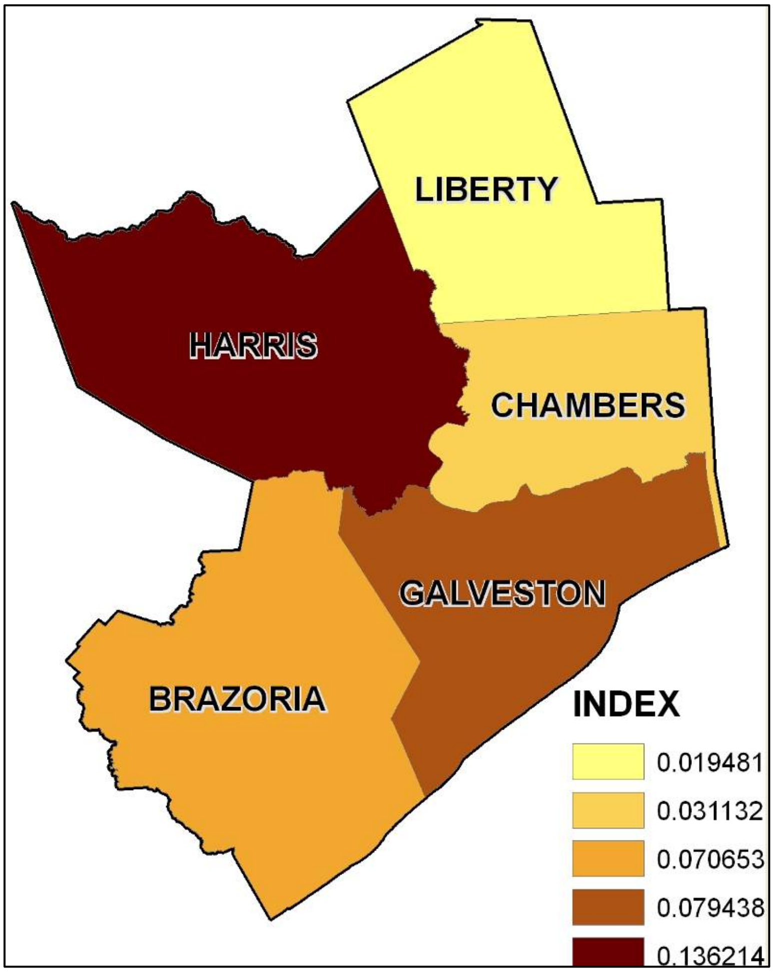

Figure 3.3.8. County-level woody land fragmentation of the Lower Galveston Bay watershed. The index (*F*) is a measure with no units and ranges from 0 to a maximum of less than five. The index can be considered as an indication of an idealized, even distribution of a number of same-sized patches over a ten hectare area.

Fragmentation by Sub Watershed

We adopted the sub watershed map used by Galveston Bay Estuary Program (See Figure 3.3.1). It divides the Galveston Bay watershed into 22 sub watersheds that are listed in Table 3.3.9. Two of these sub watersheds represent major tributaries of the bay, the Trinity and San Jacinto Rivers. Five of the sub watersheds are areas of the bay shore that have no tributaries and the remaining 15 are components of the network of small local tributaries named as bayous, creeks, and some associated flood control reservoirs.

Examination of the values in Table 3.3.9 and the maps in Figures 3.3.8 and 3.3.9 provides an interesting perspective on the relationship between human settlements and fragmented habitat. In all cases the western side of the bay is more fragmented than the eastern side. For wetlands, the watersheds along the bay are less fragmented than the watersheds associated with tributaries, e.g. North Bay compared to Buffalo and White Oak Bayous. The watersheds that are located west of the center of Houston tend to be more fragmented than those watersheds north and south, with the exception of Dickinson Bayou.

Woody habitats show a slightly different pattern than wetlands. There is still a concentration of fragmentation in the urban watersheds of Houston, but a new area of fragmentation is shown along the borders of West Bay and Lower Galveston Bay. Most of these areas are traditionally grassland. It is possible that the planting of trees and the spread of the exotic Chinese tallow tree are contributing to this result. It is likely that the Buffalo Bayou watershed is showing a smaller fragmentation index than Brays Bayou because the trees planted in residential areas in this watershed have grown to present a forest canopy in aerial photographs.

Table 3.3.9. List of Galveston Bay Sub Watersheds with the Fragmentation Indices Calculated for Wetland and Woody Land Cover Classifications.

Subwatershed	Wetland Fragmentation Index	Woody Fragmentation Index
Buffalo Bayou	0.946	0.215
White Oak Bayou	0.898	0.594
Brays Bayou	0.379	0.708
Greens Bayou	0.392	0.124
Sims Bayou	0.332	0.416
Addicks Reservoir	0.291	0.126
Barker Reservoir	0.223	0.144
San Jacinto River	0.169	0.114
Ship Channel	0.141	0.275
Cedar Bayou	0.063	0.09
Armand-Taylor Bayou	0.179	0.202
Clear Creek	0.387	0.175
Dickinson Bayou	0.607	0.166
Trinity River	0.02	0.022
Chocolate Bayou	0.243	0.115
Austin-Bastrop Bayous	0.034	0.113
North Bay	0.285	0.152
Trinity Bay	0.048	0.037
South Bay	0.119	0.346
East Bay	0.006	0.077
West Bay	0.077	0.246

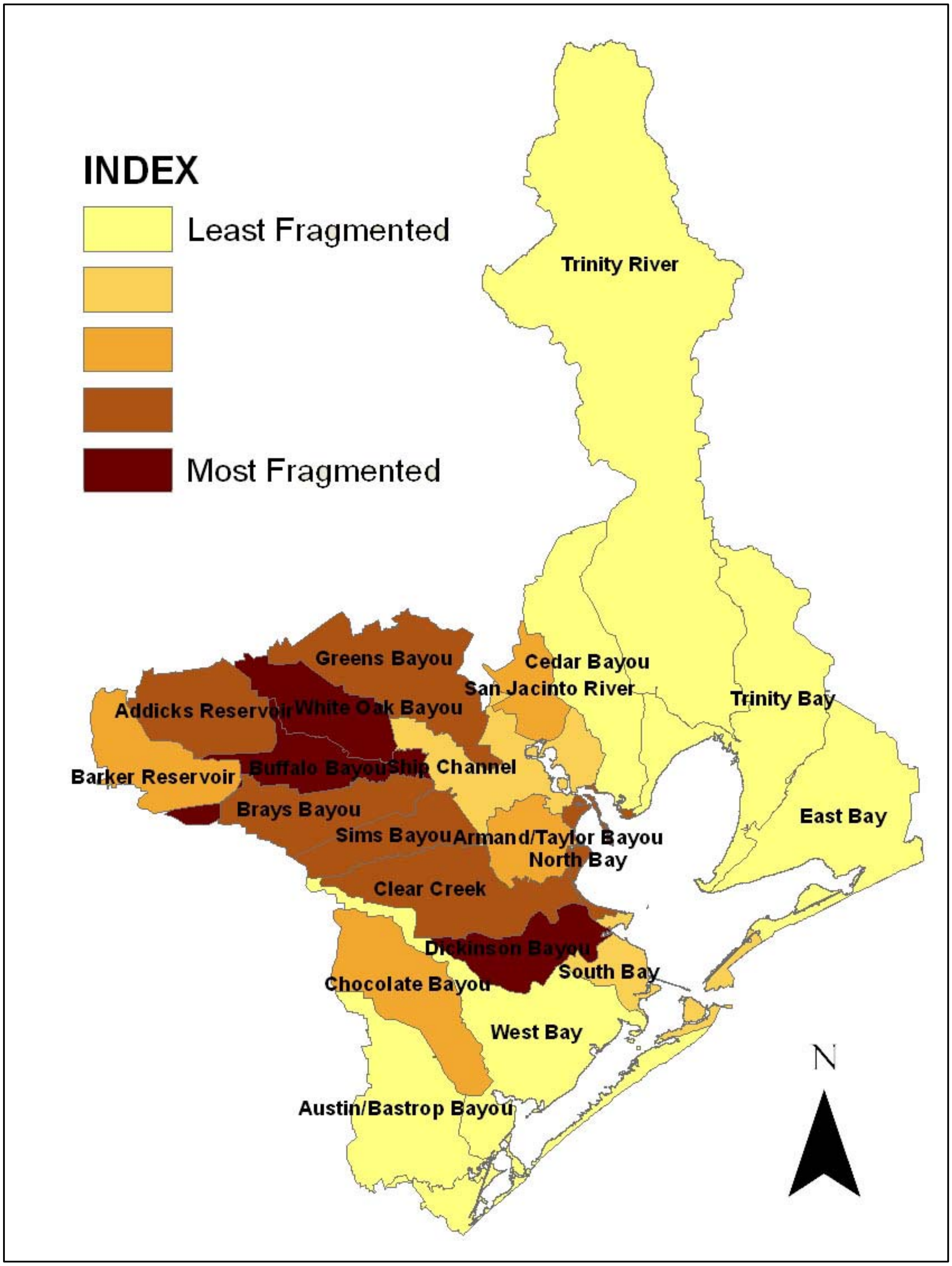

Figure 3.3.9. Subwatershed-level wetland land fragmentation of the Lower Galveston Bay watershed based on the habitat index (*F*). *F* is a measure with no units and ranges from 0 to a maximum of less than five. The index can be considered as an indication of an idealized, even distribution of a number of same-sized patches over a ten hectare area.

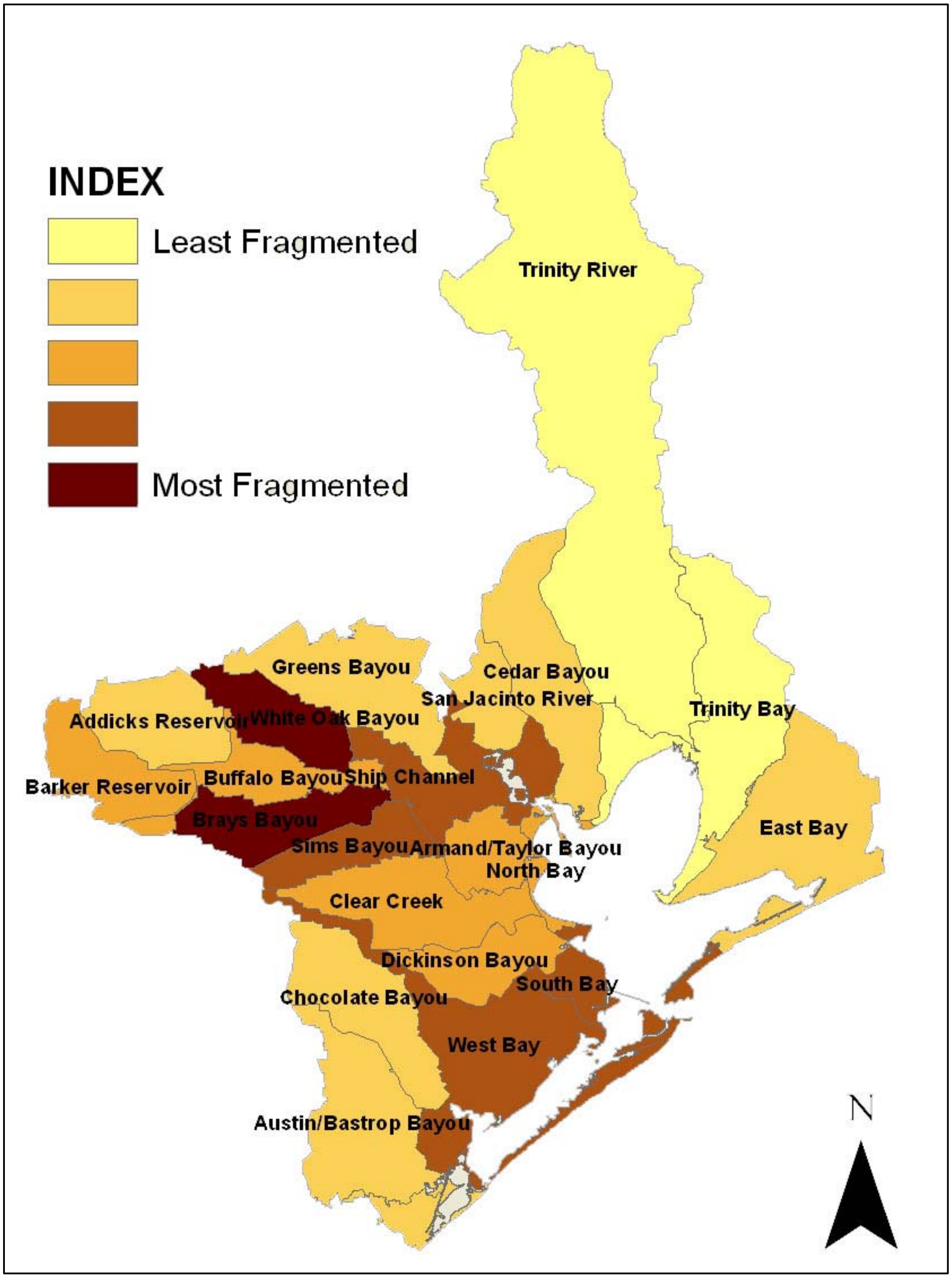

Figure 3.3.10. Subwatershed-level woody land fragmentation of the Lower Galveston Bay watershed based on the habitat index (*F*). *F* is a measure with no units and ranges from 0 to a maximum of less than five. The index can be considered as an indication of an idealized, even distribution of a number of same-sized patches over a ten hectare area.

Conclusion

The examination of fragmentation in the Galveston Bay watershed provides a useful view of the distribution of habitat types. If additional land use data sets become available, future investigations of habitat fragmentation over time will be a more powerful way of reviewing the impact of human development. This initial assessment of the status of two important habitat types can still provide a valuable tool in planning future land conversions. Those watersheds that have large areas of unfragmented wetlands and woody lands should be prioritized for conservation to reduce the impacts of increasing fragmentation on living resources in our region.

In general, the less fragmented wetland habitats are found east and south of Houston in the Galveston Bay watershed. For woody habitats, there are less fragmented areas for conservation around Clear Creek and Dickinson Bayou, as well as east and south of Houston along tributaries of the bay. It is clear that the development of Houston has been a major factor in fragmenting these habitats. As Houston and surrounding municipalities grow, information such as this should be used to inform land use planning.