Pipeline Construction Impact on Coastal Marsh Vegetation and Soils

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Abstract: Vegetation and soils were sampled 1 month prior to and 1 year after a pipeline was constructed in a Texas coastal marsh. Submerged aquatic (SAV) and emergent vegetation (EV) were sampled to detect changes in taxa frequencies and percent cover within 3 pipeline corridor treatments (soil deposit/borrow, pipeline ditch, construction equipment) and a control. Taxon richness was not significantly altered by pipeline construction within EV plots. However, pipeline construction decreased total vegetative coverage of EV plots within all 3 pipeline treatments. A 33% (2.3 ha) decrease in EV coverage was calculated within a 30.4-m strip along the pipeline ditch using pre- and post-construction aerial photographs and Geographic Information System (GIS) technology. Similarly, data from EV quadrats indicated a 49% (2.2 ha) loss within the 19.8-m wide construction corridor. No analyses were performed on SAV data because these plants were only present during pre-construction sampling. Vertical soil profiles significantly decreased within the pipeline ditch and control in SAV regions. Soil losses within the pipeline ditch may have resulted from erosion. However, decreased soil elevations within the control may have resulted from disturbances by equipment traveling outside the construction corridor. Ultimately, vegetation and soil losses within pipeline construction corridors should be expected with current double-ditching techniques.

Proc. Annu. Conf. Southeast Assoc. Fish and Wildl. Agencies 51:489–500

The most extensive, contiguous loss of wetlands along the entire Texas coast has occurred along the Lower Neches River (White et al. 1987). From 1956–1978, 3,811 ha (160 ha/year) of vegetated marshes in the Lower Neches River area were replaced by open water (White 1993). Conversion of marshes to open water has been attributed to: (1) subsidence associated with active faulting or induced by extraction of groundwater, oil, or gas (White and Tremblay 1995); (2) an accretion deficit relative to sea-level rise and sediment deposition; and (3) the direct and indirect effects of dredged canals (Morton and Paine 1990). Pipeline and navigation canals have the potential to change the natural hydrology of coastal marshes by (1) facilitating rapid drainage of interior marshes during low tides or low precipitation, (2) reducing or interrupting fresh water inflow and associated littoral sediments, and (3) allowing salt water to move farther inland during periods of high tide (Chabreck 1972). Salt water intrusion into fresh marsh often causes loss of salt intolerant emergent and submerged aquatic plants (Chabreck 1981, Pezeshki et al. 1987*b*) and erosion and net loss of soil organic matter (Craig et al. 1979).

Double-ditching was used to construct a 25.4-cm (10-inch) hydrogen pipeline through coastal marshes in Orange County, Texas, in September 1995. Double-ditching is a technique in which a dragline excavates the pipeline ditch and places the soil in piles adjacent to the trench. After placing the pipe in the trench, the operator replaces the excavated soil and attempts to maintain topsoil on the surface. Based upon qualitative observations of past pipeline construction areas where both soil and vegetation loss appeared permanent, Texas Parks and Wildlife Department (TPWD) was interested in quantifying the potential loss of sediments and changes in plant species composition and coverage associated with construction of this pipeline.

Limited research has been conducted on the response of wetland vegetation and soils to pipeline construction activities (e.g., ditching, stacking of fill, equipment travel). Revegetation rates in pipeline canals are dependent upon soil type, salinity gradients in adjacent marshes, and the type of construction equipment used (Abernethy and Gosselink 1988). Chabreck (1979) discovered double-ditching to be more effective than single-ditching in reestablishing emergent vegetation along a pipeline corridor. On the other hand, timing of backfilling canals is important: backfilling years after their construction is not effective in reestablishing emergent vegetation (EV) because the volume of spoil available for backfilling is smaller due to erosion and decomposition of organic matter (Neill and Turner 1987, Reed and Rozas 1995).

We acknowledge TI Energy Services, Inc., and TPWD for providing funding for this study. The entire staff of TPWD's Upper Coast Wetland Ecosystems Project provided assistance throughout the project. Field sampling for plant identification and percent cover estimates were contracted with Botanical Research Center (Bryan, Texas). TPWD's Geographic Information System (GIS) Lab conducted GIS analyses.

Methods

The research site was located within tidal marshes north of Sabine Lake in Orange County, Texas. It measured approximately 9.66 km in length and began at the north bank of the Neches River, extended northeast across state highway 87 and the Old River Unit of the Lower Neches Wildlife Management Area (LNWMA), and ended approximately 0.62 km east of the LNWMA. The pipeline route intersected 3 fresh to brackish marshes with predominately widgeon grass (*Ruppia maritima*) in submerged aquatic vegetation (SAV) sites and marshhay cordgrass (*Spartina patens*), smooth cordgrass (*S. alterniflora*), and salt-marsh bulrush (*Scirpus robustus*) in EV sites. Tidal regimes in the area range from 30–45 cm on average; however, extremes occur during severe weather conditions (Polasek unpubl. data).

The pipeline construction corridor was 19.8 m wide and oriented in a north-east direction. The construction corridor was divided into 3 parallel treatments (pipeline ditch, construction equipment, and soil deposit) with the pipeline ditch located in the center. Construction equipment (amphibious draglines and airboats) traveled south of the pipeline ditch and stacked excavated soil on the north side of the ditch. A 19.8-m wide control corridor was located parallel to, and south of, the construction equipment treatment.

Vegetation Sampling

Field Quadrats.—Pre- and post-construction vegetation samples were collected on 6–8 September 1995 and 30 September–1 October 1996, respectively. Along the pipeline route, 9 and 6 transects were randomly placed within EV and SAV regions, respectively. Transects were oriented perpendicular to the pipeline with 3 0.25-m^2 quadrats evenly spaced within the control corridor and 1 within each pipeline treatment. Therefore, 9 EV and 6 SAV quadrats were measured within each treatment and 27 EV and 18 SAV quadrats were measured within the control corridor during each sampling period. Plant species and percent cover estimates were recorded within each quadrat.

Plant surveys within each quadrat were used to determine species frequencies during both pre- and post-construction sampling. Species lists for control transects were cumulative for the 3 quadrats on each transect. Plant lists from each quadrat were used to determine the effects of pipeline construction on taxon richness within pipeline treatments and the control.

Visual percent cover estimates within a quadrat were recorded to the nearest 5% for each species. Total vegetative coverage was determined for each quadrat by adding individual species' coverages. Due to multiple layers or canopies, total vegetative coverage could exceed 100% within a single quadrat. Total vegetative coverage for control transects was determined by averaging individual vegetative coverages from the 3 control quadrats of each transect. Total vegetative coverage and coverages of individual plant species with ≥50% frequency of occurrence within a treatment during any 1 sampling period were used to determine changes across the treatments and control.

Geographic Information System Analyses.—Color infrared aerial photographs taken in July 1995 and September 1996 (scale: 2.54 cm = 122 m or 1 inch = 400 feet) were scanned as Tagged Image File Format digital images at a resolution of 157 dots per cm. Vegetation classification and change analyses were performed using Erdas Imagine image-processing software (ERDAS, Inc.) and Arc/Info GIS software (Environ. Systems Res. Inst., Inc.) A 1995 aerial photograph for a 1.21-km section of marsh adjacent to the Neches River was not available. Therefore, GIS analyses focused on the remaining 2.52-km of pipeline for which photography from both years was available. The 1995 images were rectified to State Plane coordinate system using ground control points collected with an Ashtech Reliance Global Positioning System (GPS). Ground control points were obtained using differentially corrected carrier phase GPS measurements. Estimated accuracy was sub-decimeter across the study area. The 1996 images were then rectified to 1995 images to ensure positional accuracy between the years.

A 30.4-m strip, centered over the pipeline ditch, was used for GIS analysis of aerial photography. The strip encompassed the entire pipeline construction corridor in addition to portions of nonconstruction areas on either side. Images were classified using an unsupervised classification algorithm in Erdas that yielded 10 to 18 classes per image depending on initial scan quality. Visual inspection of classified images resulted in the assignment of each class as either EV or water. Resulting binary images were then converted to Arc/Info polygon coverages for change analysis. Polygons measuring less than 5 pixels (1 pixel = 0.3 m) were eliminated to reduce noise resulting from the scanning process. Total EV was calculated within the 30.4-m wide zone for each year and percent change was then determined between the 2 sampling periods.

Accuracy of the GIS estimate for EV loss was examined by comparing it to EV quadrat data obtained in the field. Total percent cover change between 1995 and 1996 was determined for EV quadrats within pipeline corridor treatments. Average percent change was then calculated across the entire pipeline corridor. The EV hectare measurement, calculated with the GIS system, was within a 30.4-m wide strip. Construction activities, however, were supposed to occur within a 19.8-m wide area. Therefore, it was estimated 65% of the vegetation calculated within the 30.4-m strip occurred within the pipeline construction corridor. The change in pre- and post-construction EV cover was then calculated by multiplying the EV hectares within the 19.8-m strip by the calculated mean percent cover change within EV plots.

Soil Sampling

Pre- and post-construction soil samples were collected at each EV and SAV quadrat location. Bed material and sediment samples were collected with a sediment corer measuring either 61-cm or 91-cm long and 5.1 cm in diameter. The following soil characteristics were documented: (1) bed material or original surface color and texture (grain size percentage); (2) sediment-layer color, texture, n-value, organic matter (presence and decomposition state), presence of hydrogen sulfide gas (an indicator of anaerobic conditions in the sediment); and (3) sediment-layer thickness. Soil texture and color were determined using the U.S. Department of Agriculture (USDA) soil texture criteria and Munsell soil color charts, respectively.

The n-value applies directly to the bearing strength and stability of marsh soils, as it is a measure of the stability of soils when settled and potential loss of soils when impacted by environmental (e.g., storms and tides) and/or anthropogenic factors (e.g., pipeline construction, boat wakes, boat motor turbulence) (Pons and Zonneveld 1965). The n-value is the best method to describe soil or sediments having pores full of water; bulk density, in contrast, is simply used to describe the mass per unit volume as measured in the moist or dry state (USDA 1993). A modified n-value scale was used in this set of analyses (USDA 1993). N-values range from 0.7 (strongly stable, clay or silty clay) to 1.0 (strongly unstable, mucky silt or organic mat). The modified scale was used because the separation between samples was very distinct. Based on the modified scale, soil layers with n-values greater than 0.8 (slightly unstable, mucky silt, or silt) would easily be placed into suspension by either environmental or man-induced activities. Also, these soil layers would be most susceptible to loss during pipeline construction activities. The thickness of each sediment layer was measured and total plug thickness was determined by summing measurements from individual layers.

Statistical Analyses

Taxon richness, total-vegetative coverage, and soil thickness were analyzed for statistical normality with the Shapiro-Wilk statistic and box plots (PROC UNIVARIATE; SAS Inst. Inc. 1987). Data were non-normal; therefore, a non-parametric analysis of variance (PROC NPAR1WAY; SAS Inst. Inc. 1987) was used to test for differences ($P = 0.05$) in response variables across pipeline treatments and the control during pre- and post-construction sampling.

Results and Discussion

Vegetation Taxon Richness

EV Plots.—Pipeline construction appeared to have little or no effect on taxon richness within EV regions. Twenty-four and 20 taxa were recorded within 1995 and 1996, respectively (Polasek 1997). Marshhay cordgrass and salt-marsh bulrush occurred most frequently. Taxon richness did not differ between pipeline treatments and the control during pre- ($P = 0.66$) or post-construction ($P = 0.08$) sampling. In addition, analyzing data by pipeline treatments across pre- and post-construction sampling revealed no significant changes in taxon richness for pipeline ($P = 0.23$), equipment ($P = 0.49$), or soil deposit ($P = 0.35$) treatments. Likewise, taxon richness did not change ($P = 0.63$) between sampling periods within the control corridor. Taxa numbers did not significantly change between 1995 and 1996 because species lost from 1995 were replaced by colonizing species in 1996.

SAV Plots—Widgeon grass, Eurasian water-milfoil (*Myriophyllum spicatum*), coontail (*Ceratophyllum demersum*), sago pondweed (*Potamogeton pectinatus*), and thinleaf pondweed (*P. pusillus*) were recorded during 1995 sampling with widgeon grass and Eurasian water-milfoil exhibiting highest frequencies of occurrence (Polasek 1997). During 1996, however, no submerged aquatics were recorded in either the control or pipeline treatments. Total loss of SAV probably was due to high salinity (10.5 ppt) resulting from low rainfall (Polasek 1997). Monthly precipitation levels between January and May 1996 totaled 18.5 cm; 65% below the normal of 52.6 cm for the area. Coontail only occurs in fresh marshes ($\bar{x} = 1.0$ ppt) and thinleaf pondweed can only survive in fresh to intermediate marsh ($\bar{x} = 3.3$ ppt) conditions; Eurasian water-milfoil, sago pondweed, and widgeon grass, however, can live in brackish ($\bar{x} = 8.2$ ppt) marshes (Hotchkiss 1972, Chabreck and Condrey 1981, Chabreck 1990). However, these species tend to require fresher conditions during germination (Stutzenbaker, in prep.). Due to a lack of submerged aquatics during 1996, no additional analyses involving SAV taxon richness or percent coverage measurements were conducted.

Vegetation Coverage

Mean EV coverage (total vegetative coverage) did not differ ($P = 0.92$) between pipeline treatments or the control during 1995 (Fig. 1a). However, in 1996, 1 year after pipeline construction, EV plots within the pipeline ditch, construction equipment, and soil deposit treatments supported lower ($P = 0.006$) mean-vegetative coverages than did the control. Vegetative coverages were lowest within the pipeline ditch.

After reviewing taxa frequency data, one could hypothesize that environmental factors may have had a greater influence on total-vegetative coverages than did

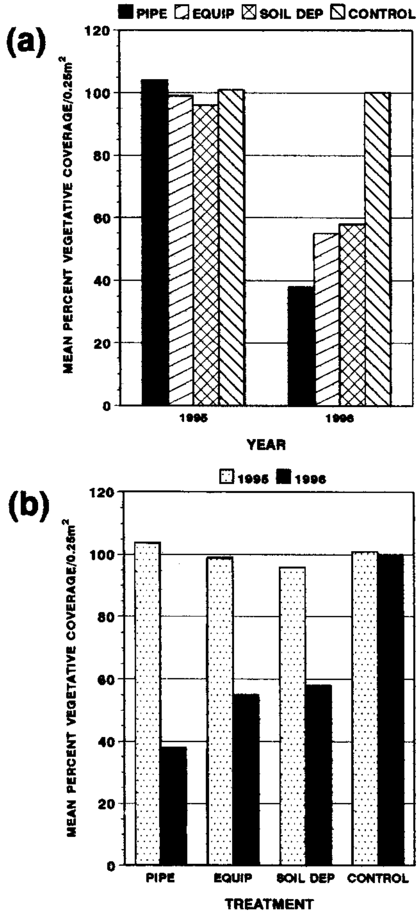

Figure 1. Mean percent vegetative coverages for emergent vegetation plots (a) within years across the control, pipeline ditch, construction equipment, and soil deposit treatments (PIPE, EQUIP, and SOIL DEP, respectively); and (b) within the control and treatments between years.

pipeline construction. Therefore, total-vegetative coverages were compared between 1995 and 1996 within the pipeline treatments and control. EV coverage decreased in pipeline ditch, construction equipment, and soil deposit treatments ($P = 0.001$, $P = 0.03$, $P = 0.01$, respectively) 1 year after pipeline construction (Fig. 1b). However, total vegetative coverages did not change ($P = 0.89$) within the control corridor after pipeline construction. Therefore, changes in total vegetative coverage within pipeline corridor treatments were predominantly due to disturbances from pipeline construction. Four of the 9 pipeline ditch quadrats were void of any vegetation 1 year after pipeline construction.

GIS analyses revealed 7.0 ha of emergent vegetation within the 30.4-m strip prior to pipeline construction. However, in 1996 only 4.7 ha remained. Therefore, a 33% loss of EV was attributed to pipeline construction. Two possible sources of error exist involving the estimate of EV loss obtained with the GIS. First, marsh habitats generally do not contain easily identifiable ground control points to rectify aerial photographs. Tighter ground control, possibly through the use of ground panels, would have benefited the rectification process. Second, the corridor used to estimate vegetation loss was very narrow (30.4 m) despite a photographic scale of 2.54 cm = 122 m.

Although confidence intervals could not be calculated, the GIS estimate of 2.3 ha EV loss corresponds well with calculations from EV quadrat data. The 1995 GIS estimate of EV coverage within the 30.4-m strip was 7.0 ha. The adjusted (65%) EV coverage within the 19.8-m wide pipeline corridor was 4.6 ha. Based upon EV quadrat data, mean emergent coverage decreased by 49% or 2.2 ha within the pipeline corridor. Therefore, the 2.3 ha estimate calculated with GIS appears highly accurate.

The only plant occurring frequently enough to allow a species level analysis was marshhay cordgrass. Marshhay cordgrass did not differ in vegetative coverage between the control and pipeline treatments in 1995 ($P = 0.99$) or 1996 ($P = 0.15$), nor did its coverage change within the construction equipment ($P = 0.10$), soil deposit ($P = 1.0$), or control corridors ($P = 0.80$) between 1995 and 1996. However, it did decrease ($P = 0.01$) in coverage within the pipeline ditch 1 year after construction. Decreased coverage within the pipeline ditch was primarily the result of construction activities and not environmental changes because marshhay cordgrass coverage did not change within the control. If decreased coverage was due to increased salinities within the marsh, marshhay cordgrass would have decreased within all sample plots because of impaired photosynthetic processes (Pezeshki et al. 1987*a*, Pezeshki and DeLaune 1993).

Soils

Soils within SAV and EV sites consisted of mucky silt (organic mat), silt, silty clay loam, sandy clay loam, silty clay, and clay textures. Soil colors included hues: 10YR, 2.5Y, 5Y, and Gley 1; values ranging from 8 to 2.5; and chromas ranging from 8 to N (neutral). A general description of soil colors included: black, very dark gray, dark gray, gray, light gray, olive gray, greenish gray, and white. The n-values, which corresponded closely with soil texture, ranged from 0.7 to 1.0.

Hydrogen sulfide (H_2S) gas was present at the majority of sample sites during each year. Therefore, soil profiles were stable (nonmixed) for a long enough period to allow oxygen levels to decrease from the levels that were present when the sediment was deposited. Sulfates (SO_4^{2-}) are not toxic to plants at natural concentrations; however, reduced states of sulfate (H_2S, HS^-, and S^{2-}) created by anaerobic conditions are toxic (Pezeshki et al. 1988).

Within the majority of the soil profiles, roots ranged from few to common in the upper 25.4 cm to none or few in the lower 12.7 cm. Organic mats usually corresponded to the occurrence of many roots. Organic matter states of decomposition included: sapric (fine), hemic (medium), fibric (coarse fibers), or no organic matter present. Organic mats usually corresponded to fibric/hemic conditions with coarse and medium organic matter fragments being present in the soil profile. The most distinct difference in soil characteristics between the SAV and EV sites was the increased amount of roots and organic matter in the EV sites, which coincided well with the presence of live emergent plants.

Pipeline construction appeared to have little or no effect on soil thickness within EV sites. Soil thickness did not significantly differ between pipeline treatments and the control during pre- ($P = 0.34$) or post-construction ($P = 0.28$) sampling. In addition, tests for changes in soil thickness within treatments between years did not produce significant results within the control ($P = 0.44$), pipeline ditch ($P = 0.20$), equipment ($P = 0.10$), or soil deposit ($P = 0.06$) treatments.

Results within SAV sites were very similar to those from EV sites. Soil thickness did not significantly differ between pipeline treatments and the control during pre- ($P = 0.73$) or post-construction ($P = 0.60$) sampling. Soil thickness did not differ between pre- and post-construction sampling within equipment ($P = 0.06$) or soil deposit ($P = 0.26$) treatments. However, significant differences were detected within the control corridor ($P = 0.01$) and pipeline ditch ($P = 0.04$). Soils were thicker on average in 1995 ($\bar{x} = 54.89$ cm, SE = 0.18 cm, $N = 6$) than in 1996 ($\bar{x} = 49.96$, SE = 0.60, $N = 6$) within the control corridor. Similarly, soil thickness decreased between 1995 ($\bar{x} = 55.45$ cm, SE = 0.17, $N = 6$) and 1996 ($\bar{x} = 42.98$, SE = 2.09, $N = 6$) within the pipeline ditch.

Sixty-one percent of soil samples from SAV plots within the 3 pipeline treatments and the control decreased in soil thickness. Average decreases within the control corridor ranged from 3%–16% (1.7–8.9 cm), while decreases within the pipeline ditch ranged from 0–59% (0–33 cm). A decrease in soil thickness within the pipeline ditch could be expected due to construction activities. Soils could have washed away because they never had a chance to consolidate as they were almost continuously covered with water. In addition, soil excavated from the site likely lost volume due to drying and decomposition of organic matter (Neill and Turner 1987). The surprising factor was the loss of soil thickness within the control. If the loss was entirely due to environmental factors, the same results would have been expected within each of the pipeline treatments because each was subjected to the same environmental factors plus disturbances associated with the pipeline construction. Decreases in soil thickness within the control may have been caused by disturbances from construction equipment which TPWD employees observed traveling outside the construction corridor on several occasions.

Conclusions and Management Recommendations

During the 1-year study, investigations clearly showed that pipeline construction, at least for the short term, reduced both EV coverage and soil elevation within the study area. GIS data indicated a loss of 33% or 2.3 ha of EV. Likewise, an estimate based on EV coverage from field surveys indicated a 49% or 2.2 ha loss within the pipeline construction corridor. EV loss is significant because researchers in other coastal marshes determined that only partial revegetation occurred even 4 years after pipeline construction (Abernethy and Gosselink 1988, Knott et al. 1997). Therefore, revegetation rates in coastal marshes can be very slow after pipeline construction.

Soil loss in the pipeline ditch can cause additional problems in the remainder of the marsh. Initial decreases in soil elevations in this study may have been due to erosion or the decomposition of roots from live plants disturbed during construction (DeLaune et al. 1994). Unfortunately, sections of the pipeline lie parallel to the direction of tidal flow. Therefore, when tide water enters and leaves the marsh, it travels the pipeline ditch and further reduces soil elevations by erosion. Erosion is often a major factor reducing marsh elevations in vegetated regions, particularly along edges where wave or tidal energy undermines emergent plants (Stevenson et al. 1985, Nyman et al. 1994). Losses in elevation probably were not due to compaction because semi-fluid soils with n-values greater than 0.7 cannot be compacted under saturated conditions and these sediments comprised the majority of the layers in the core samples. Clay layers with n-values of 0.7 can be compacted. However, they occurred underneath the other layers and only comprised a small percentage of the sediment in the cores.

In the future, continued erosion of the pipeline ditch could establish a major channel for water movement within the marsh. Coastal marshes divided by straight ditches and canals are exposed to drastic tidal action allowing salt water to move farther inland and fresh water to drain faster from interior regions (Chabreck 1988). Salt water intrusion poses a significant problem because seawater is the primary source of sulfate (Feijtel et al. 1988) and when combined with increased anaerobic soil conditions due to flooding, toxic soil conditions can develop and limit plant production (Connell and Patrick 1969, Pezeshki et al. 1988, Feijtel et al. 1989).

Decreased plant production can lead to further marsh degradation and loss. Accretion from organic matter can be just as important as mineral matter accumulation to counter marsh submergence (Nyman et al. 1993*a*, *b*). Inadequate organic matter accumulation results from inadequate plant production due to flooding stress. A negative feedback loop develops because inadequate plant growth limits vertical accretion, which further increases flooding stress and decreases plant production. The degree of plant inundation and soil loss dictates the success of restoring deteriorated marshes (Mendelssohn and McKee 1989). Therefore, once disturbances within a marsh remove vegetation and reduce soil elevations, it is difficult, if not impossible, for the marsh to return to pre-construction quality.

Based upon vegetation and soil data, it is apparent that double-ditching techniques used in pipeline construction can directly impact vegetation and soils in coastal marshes. Immediate loss of emergent marsh is only part of the problem. The combination of vegetation and soil loss can have tremendous effects that persist, and even accelerate, well into the future. Unvegetated trenches created by pipeline construction can alter natural hydrology and further degrade marshes.

This study was solely designed to test for pipeline construction impacts on revegetation and soil elevations; therefore, the effects of the drought in 1996 on these factors could not be determined. Data revealed that pipeline construction did have negative short-term effects in the marshes. However, further annual sampling is needed on the study pipeline as well as on other pipelines under normal precipitation conditions to quantify suspected long-term effects on the marsh. In addition, future research should be conducted to determine alternate construction techniques to prevent the loss of marsh vegetation and soils.

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