Oilfield Produced Water

An Assessment of Produced Water Impacts at Two Sites in the Galveston Bay System

R. Will Roach
U.S. Fish and Wildlife Service, Division of Ecological Services,
Houston, Texas
and
R. Scott Carr
U.S. Fish and Wildlife Service, National Fisheries Contaminant Research Station,
Corpus Christi, Texas
and
Cynthia L. Howard
University of Houston - Clear Lake

In the process of recovering oil and gas, water is also withdrawn from underground formations. The American Petroleum Institute estimates that in stripper oil well operations approximately nine barrels (1 bbl = 42 gallons) of water are recovered for each barrel of oil. This water-oil mixture is usually separated by floatation or gravity separation in tank batteries, heat separation, skimming pits, or some combination of these methods. The remaining water, called produced water or oilfield brine, can be either deep-well injected or discharged to surface waters, as permitted.

A common method of brine disposal along the Texas coast is discharge to surface waters, either directly or by overland flow. Historically, brines discharged into freshwater or intermittent streams have caused such obvious water quality problems, primarily in water used for drinking or livestock watering purposes, that this disposal is currently restricted to tidally-influenced water bodies. This disposal method is known in Texas as "tidal or tidewater disposal."

Texas Railroad Commission (TRC) 1991 data indicated that the Galveston Bay system and its tributaries were permitted to receive up to 363,000 barrels (15.2 million gallons) of produced waters per day from 93 permitted sources. This data provided only a very gross estimate (probably overestimates) of actual discharge volumes because they are based on annual tests of well potential rather than actual flow rates. The actual volumes discharged into the bay vary greatly, depending upon the economic feasibility of oil production and the length of reservoir production (i.e., older fields yield proportionally more water).

Produced waters typically contain high levels of dissolved solids ranging in salinity from 12 to 180 parts per thousand, metals concentrations higher than those of receiving waters, and up to 25 parts per million (ppm) oil and grease. Radioactive isotopes are also prevalent in produced waters. Concentrations of radium 226 in brines may exceed regulatory criteria established for other industries. The TRC issues tidal disposal permits, provided that the discharge meets applicable Texas Surface Water Quality Standards. The Environmental Protection Agency (EPA) currently does not regulate these discharges under its National Pollutant Discharge Elimination System (NPDES).

Impacts to wetland vegetation are the most obvious signs of environmental effects resulting from brine spills or discharges. Emergent marsh plants such as smooth cordgrass and gulf cordgrass are easily killed, even by small volume or intermittent discharges. These "burned" marsh areas are the result of sodium accumulation in soils and may take years to revegetate. Produced water effects on unvegetated areas (bayous, bay margins, and open bays) are not as apparent, but possibly as severe.

Recent studies of the effects of brine upon estuarine systems have shown that: 1) high levels of dissolved solids allow the formation of a density gradient, especially in low energy systems such as bayous; 2) oil and chlorides are incorporated into sediments near discharges, severely depressing the abundance and richness of benthic infauna; 3) elevated salinities inhibit nekton movement; and 4) petroleum hydrocarbons are ingested and incorporated into the tissues of various aquatic organisms. King (USFWS, unpublished data) found that migrant shorebirds accumulated polynuclear aromatic hydrocarbons 24-fold while overwintering and feeding in the vicinity of produced water discharges.

The objective of this study was to provide a general assessment of any adverse environmental effects resulting from tidal disposal of produced waters by: 1) documenting any alterations to the benthic macroinvertebrate communities; 2) physically and chemically characterizing impacted and unimpacted sediments; and 3) assessing the toxicity caused by these discharges.

Sites at Tabbs Bay (a shoreline discharge) and Cow Bayou were selected for characterization within the Galveston Bay system (Figure 1) due to their discharge volumes. Transects were established radiating from the discharge into Tabbs Bay. A reference site was located approximately four miles away in upper Galveston Bay. Four stations in Cow Bayou and two stations in Robinson Bayou (a reference bayou influenced by urban runoff) were selected to assess impacts upon bayou habitats.

Sediment samples were collected for residue analyses of organic and inorganic constituents using a 4-inch diameter coring device. Total organic carbon, acid volatile sulfides, and grain size analyses, were conducted on sediment samples to provide indices of contaminants' bioavailability. A suite of bioassays were conducted using sediment interstitial water samples (pore waters) and resuspended and solid-phase sediment bioassays. These tests were conducted using sea urchins (*Arbacia punctulata*), burrowing amphipods (*Grandidierella japonica* and *Hyallela azteca*), and the grass shrimp (*Palaemonetes pugio*). Scores of morphological development at different dilutions was the endpoint for the sea urchin tests, while survival was the primary endpoint for the amphipod and grass shrimp bioassays. Five replicate core samples were collected at each station for macroinvertebrate

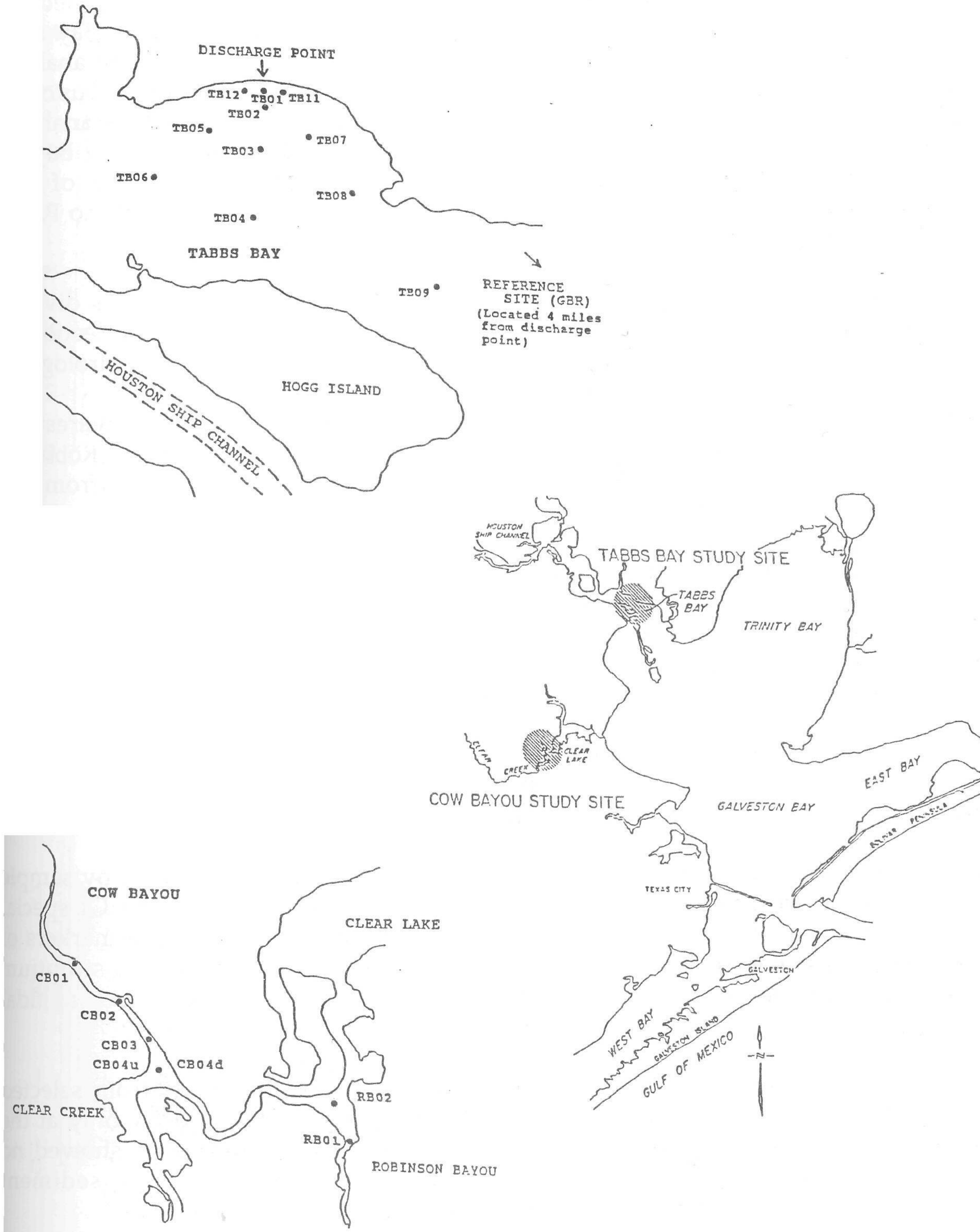

Figure 1. Location of Cow Bayou and Tabbs Bay study sites and sampling stations, Harris County, Texas.

identification and enumeration using a modified Mackin 2-inch coring device. These samples were preserved, sieved with a No. 60 mesh screen and stained for identification. Benthic infauna data for both the Cow Bayou and Tabbs Bay sites were tested for normal distribution. Data was log (x+1) transformed prior to analysis of variance (ANOVA). Mean separations were determined using Duncan's multiple range test (α=0.05). Selected tissue samples were also collected for analysis. Striped mullet were collected from discharge-impacted (Tabbs Bay and Cow Bayou) and reference sites (Christmas Bay and Robinson Bayou) for analysis of bile polycyclic aromatic hydrocarbon (PAH) metabolites, indicators of exposure to PAHs in the water column.

In Cow Bayou, the sampling station at its confluence with Clear Creek was divided into upstream and downstream stations (CB04u and CB04d) for the collection of benthos only. This was done to further assess any effects attributable to hydrology.

Benthic macroinvertebrates ranged in number from $0/m^2$ at the station nearest the discharge to $5,314/m^2$ at CB04u. By comparison, there were $14,760/m^2$ in Robinson Bayou, the reference site. The average number of species identified ranged from 0 to 6.4. Diversity, as calculated by the Shannon-Weaver function, was 0 nearest the discharge and 1.43 at the reference station, RB02. Stations differed significantly ($p<0.0001$) at both the Cow Bayou (df=40) and the Tabbs Bay (df=31) study sites. Abundance (log (x+1) transformed) showed significant mean differences for stations CB01, CB02, and CB03 versus the reference stations in Robinson Bayou. Figure 2 shows an apparent (but not statistical) difference in abundance between both CB04u and CB04d, and the reference stations RB01 and RB02. Species richness between all other stations differed significantly from the reference station RB02 (Figure 2). Diversity followed the same pattern: stations were significantly different with stations RB01, RB02 and CBO4u (the upstream confluence station) showing significantly greater mean diversities (Figure 2).

The aromatic and aliphatic hydrocarbon analytical results were summed by sample station and are presented with the oil and grease analyses in Figure 3. Of special interest in the trace metals scans are barium and strontium, as they are markers of brine discharges (Figure 4). In stable salinity regimes, both barium and strontium precipitate from the water column. Where salinity is more variable, such as tidal bayous, only strontium is found elevated in sediments.

Solid-phase bioassays conducted with grass shrimp using sediments from selected stations in Cow Bayou and Robinson Bayou showed significant toxicity only at the station nearest the discharge, CB01. Resuspended sediment bioassays showed no significant impact at any station, while benthic communities and sediment chemistry analyses revealed a great degree of impact for all of Cow Bayou.

The results for Tabbs Bay are presented for only the center transect: the results from the other transects added minimal information about the plume effect. Differences between stations were significant ($p<0.0001$) for each parameter. The center transect,

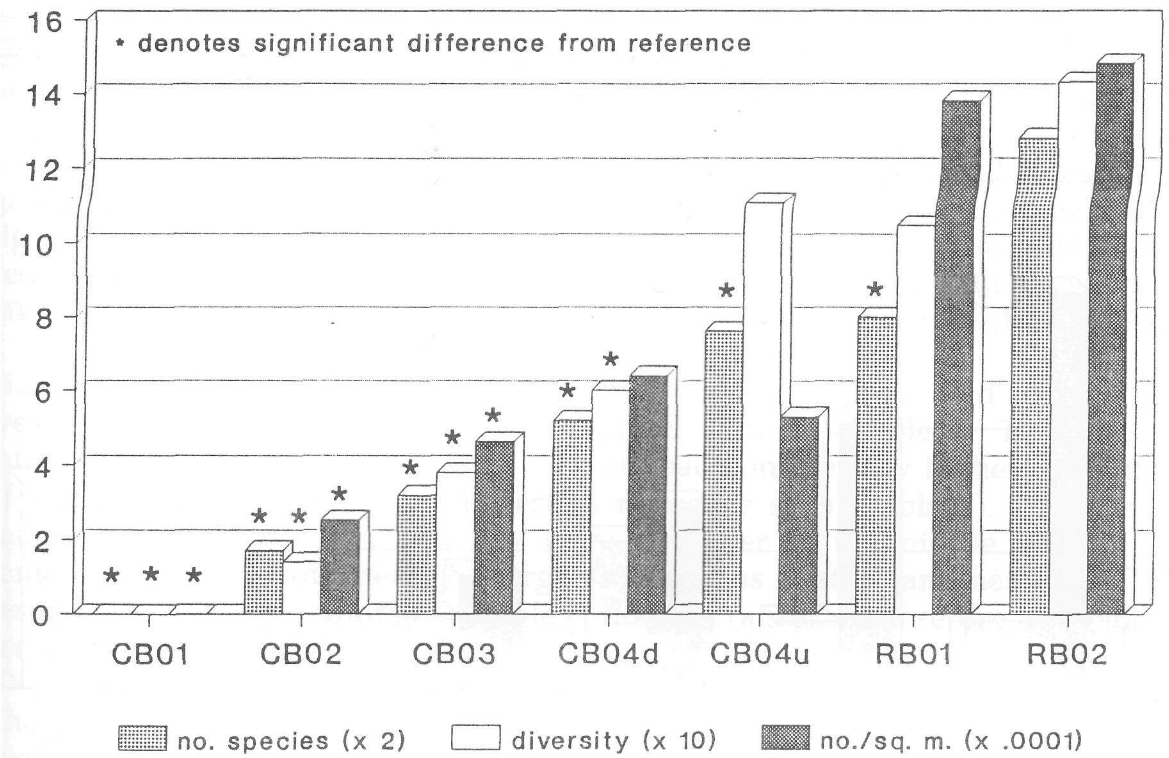

Figure 2. Cow Bayou benthic community parameters.

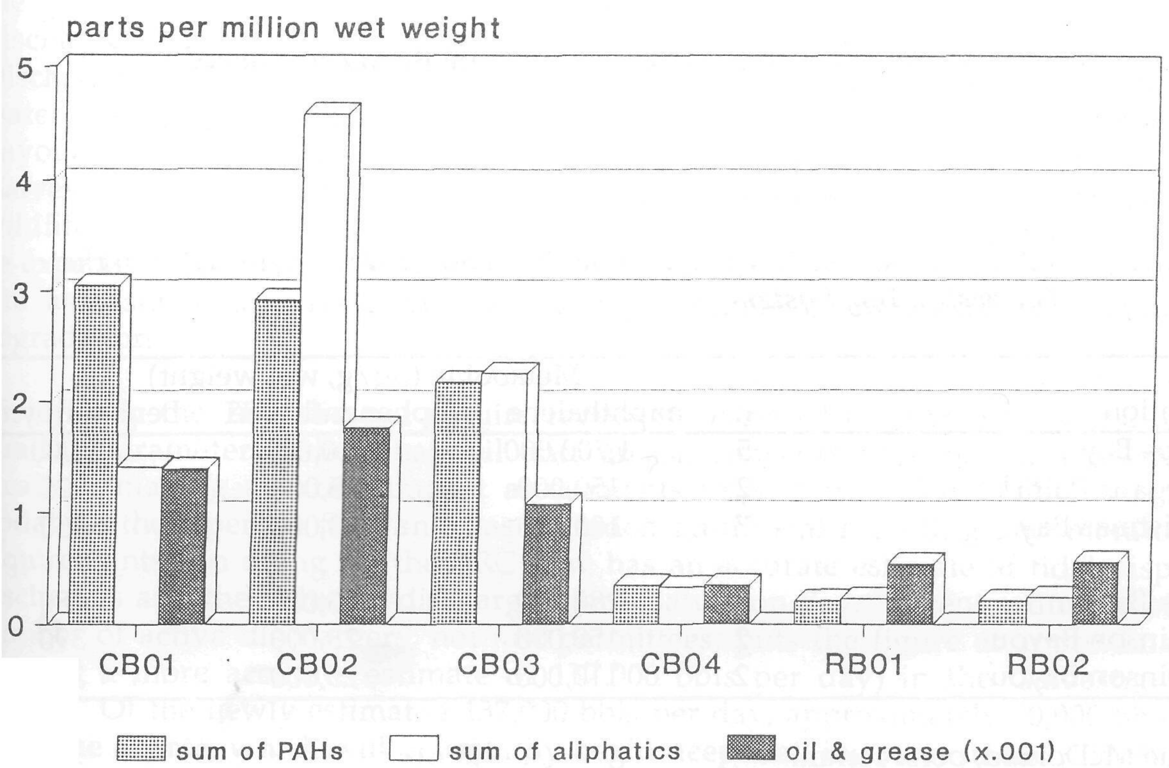

Figure 3. Organic analyses results for Cow Bayou sediments.

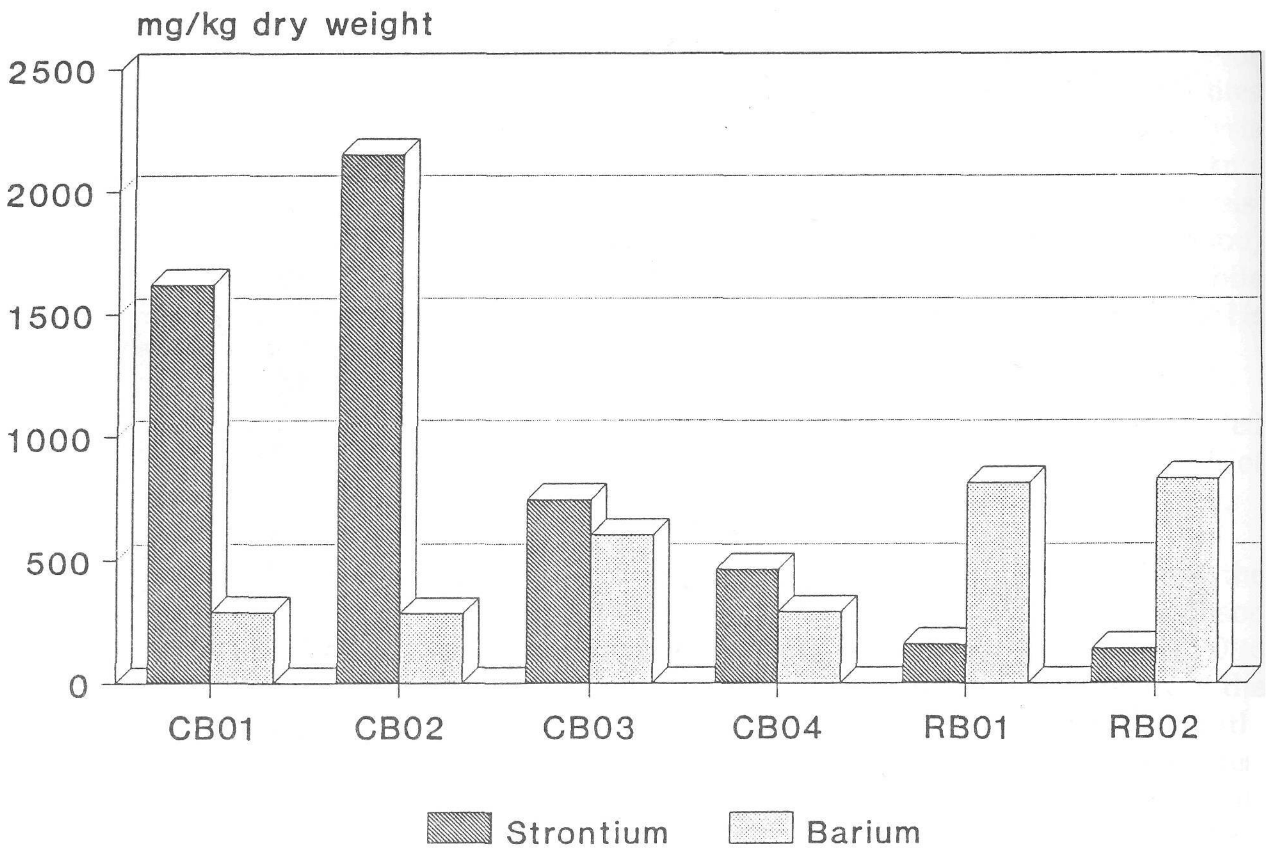

Figure 4. Strontium and barium in Cow Bayou sediments.

Table 1. *PAH metabolites in striped mullet bile collected from five sites in the Galveston Bay System.*

Location	n	Metabolite (ng/g, wet weight) naphthalene	phenanthrene	benzo[a]pyrene
Tabbs Bay	5	1,700,000	210,000	1,000
Morgans Point[1]	2	150,000	35,000	425
Christmas Bay	7	100,000	20,000	550
Cow Bayou	7	280,000	50,000	680
Robinson Bayou	2	150,000	23,000	390
Robinson Bayou	2	110,000	25,000	330

[1] Sue McDonald, pers. comm.

stations TB01-TB04, showed significantly reduced abundance, richness and diversity (Figure 5) at stations TB01 and TB02 nearest the discharge. Barium and strontium in sediment was highest at the station nearest the discharge and gradually diminished to background levels at the furthest stations (Figure 6). Residue analyses for PAHs and aliphatic hydrocarbons were again summed and are presented with oil and grease results in Figure 7. Sediment and pore-water toxicity data indicated significant impact within 370 meters of the Tabbs Bay discharge (Figures 8 and 9). Sediment interstitial water, or pore water, collected for toxicity testing had increased salinity and ammonia concentrations at stations near the discharge (Figure 10).

Biliary metabolites of the PAHs naphthalene, phenanthrene, and benzo[a]pyrene were quantified for five composite striped mullet samples. The two brine-influenced sites, Tabbs Bay and Cow Bayou, had considerably higher concentrations of each metabolite than their respective reference sites (Table 1). Metabolites in samples collected from Tabbs Bay were an order of magnitude higher than in samples collected from nearby Morgan's Point, as part of another study. These results represent composite samples, not averages. Therefore, no statistical comparisons were made.

The independent results of benthic community analyses, sediment chemistry analyses, and sediment and pore-water toxicity tests clearly show that produced water discharges contaminate sediments near them to the extent that infauna are absent or only minimally colonizing them. The most important factor governing the magnitude and extent of contamination or biological impairment caused by any discharge is the degree to which it is mixed into the receiving water body. Discharges to the open Gulf and open bay are better mixed by tidal currents and water depth than discharges to slow-moving bayous and protected shorelines. Bayous and shorelines receive a large proportion of brines discharged in the Galveston Bay system and they are typically more important habitats to fish and wildlife resources. Because of their poor mixing, a greater potential for impact can be expected. Future management of this type of discharge should include a detailed site assessment and recommendations to eliminate or minimize environmental degradation.

Historically the TRC did not require reporting of actual discharge volumes, water quality parameters other than oil and grease concentration, or exact discharge location, making accurate impact assessments impossible. The TRC is currently updating their permit files and has included additional reporting and monitoring requirements. In doing so, the TRC now has an accurate estimate of tidal disposal discharges and the volumes discharged into Galveston Bay. Recent estimates of the number of active dischargers, not just permittees, puts the figure at approximately 62 (and a more accurate estimate of 137,000 bbls per day) in the Galveston Bay system. Of the newly estimated 137,000 bbls per day, approximately 80,000 bbls are from one source, which will voluntarily begin deep-well injection in early 1993.

Although the EPA does not currently regulate these discharges under its NPDES

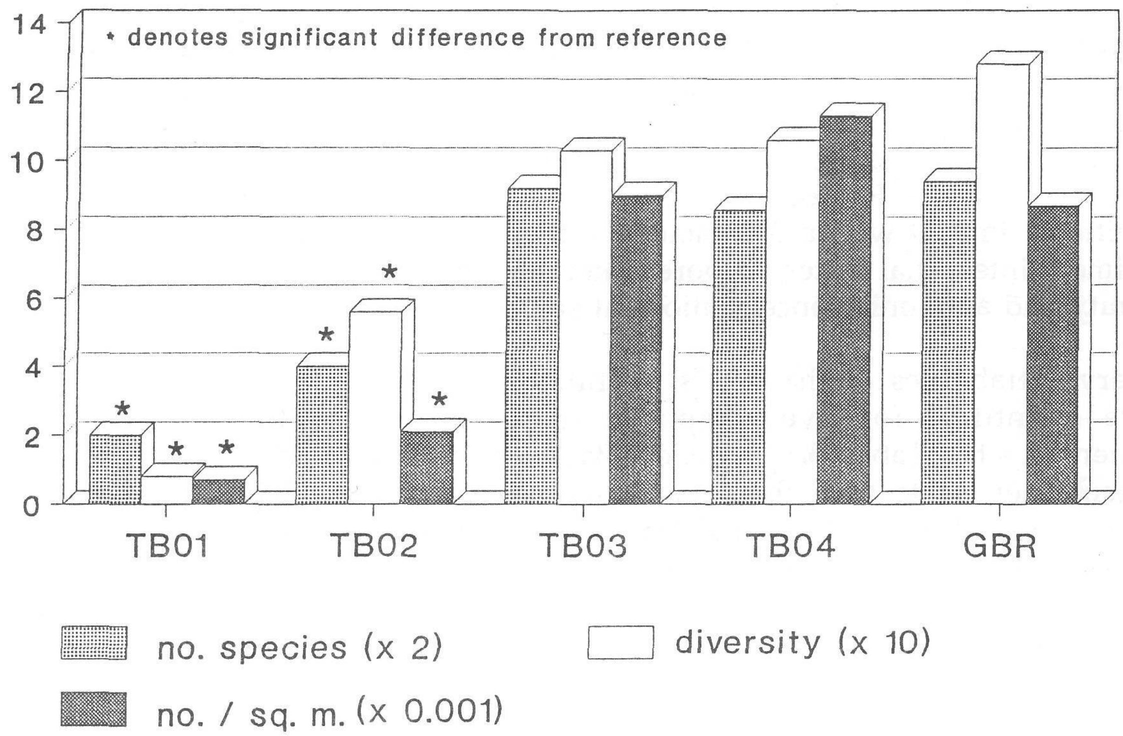

Figure 5. Tabbs Bay benthic community parameters.

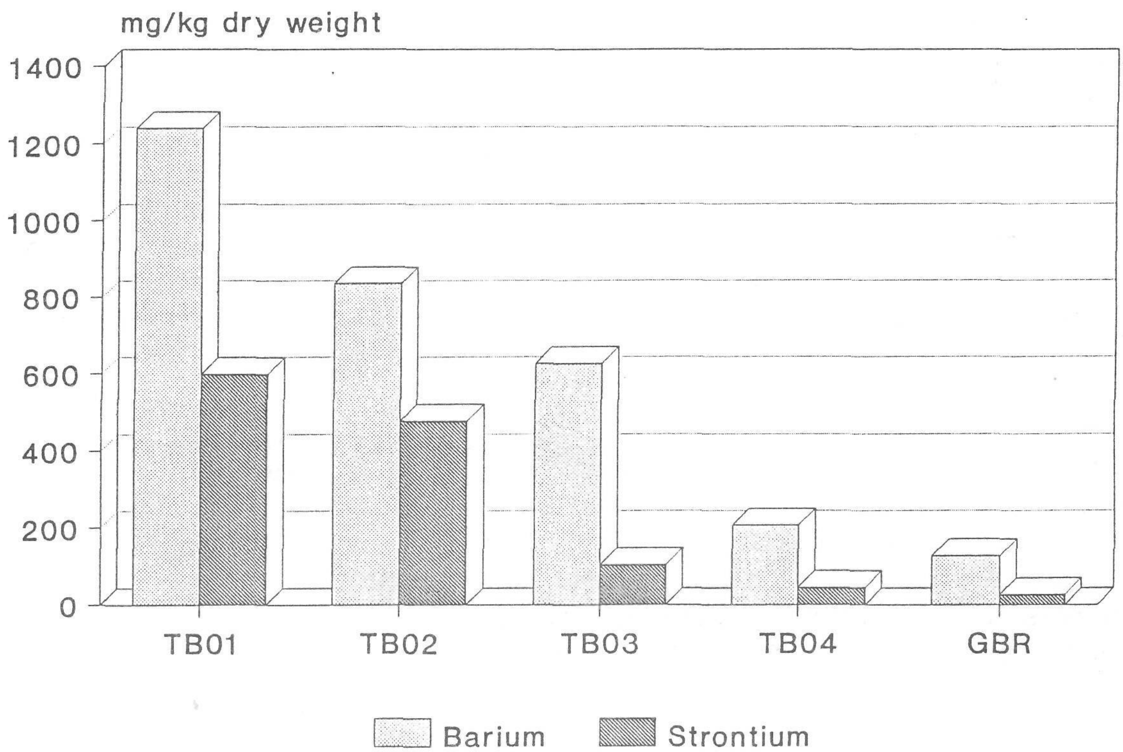

Figure 6. Barium and strontium in Tabbs Bay.

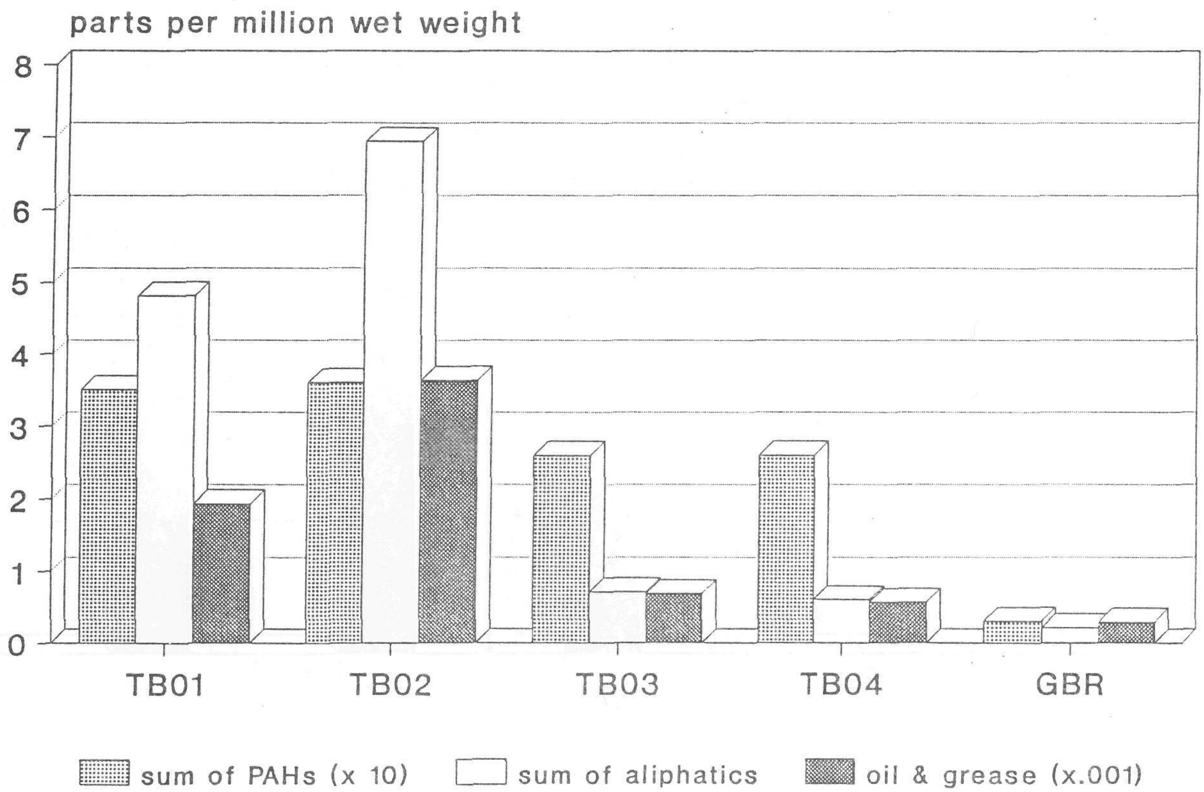

Figure 7. Organic analysis results for Tabbs Bay sediments.

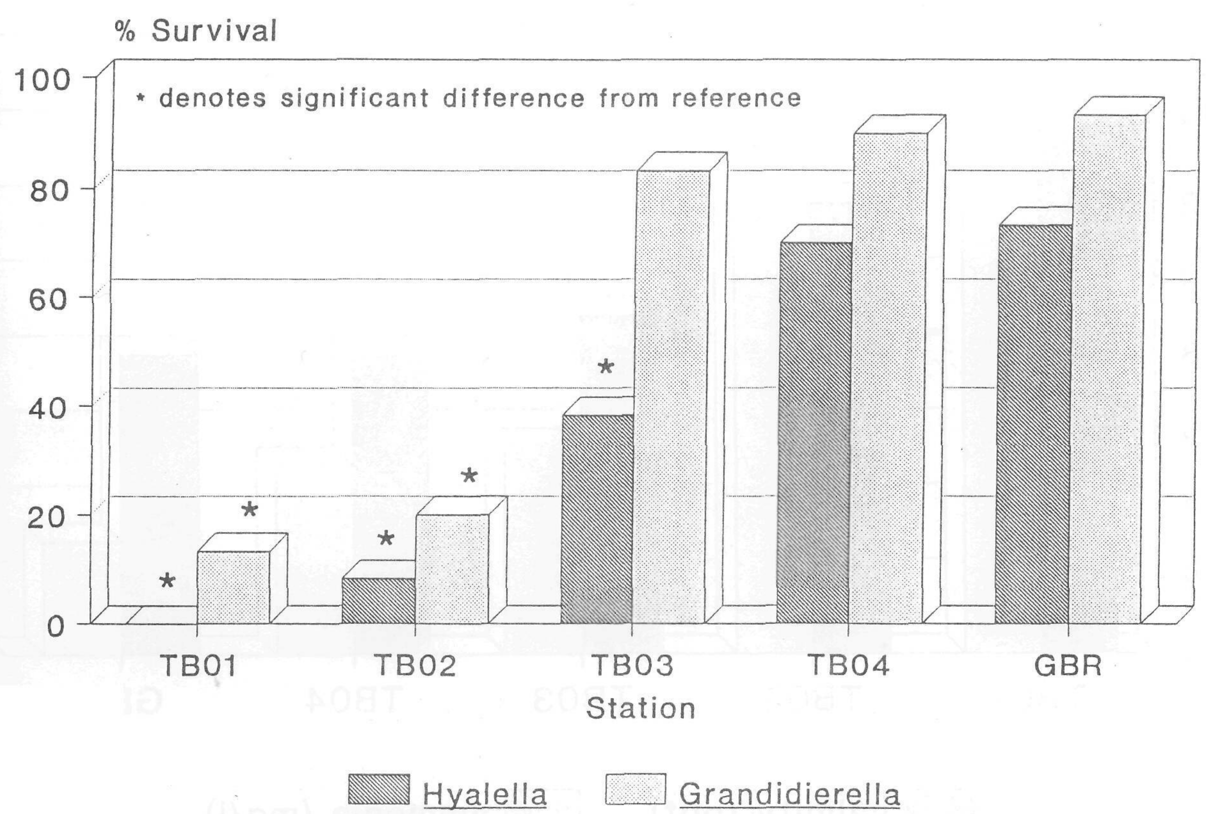

Figure 8. Amphipod bioassay results for Tabbs Bay.

program, they are drafting general NPDES permits for each of the five discharge subcategories. The one of concern for the Galveston Bay system, the Coastal Subcategory, soon will be issued as a proposed rule, open for public comment. As currently drafted, this proposed rule will require "no discharge" to marshes, wetlands, swamps, bayous or coastal bays from all wells, including stripper wells. The Onshore Subcategory, which has a similar no discharge limitation (except for stripper wells) became a final rule on March 27, 1991.

Relationship Between the Stress Protein Response in Grass Shrimp and Pollution Tolerance in Galveston Bay

Cynthia L. Howard and Kenneth R. Whitt
University of Houston - Clear Lake
and
R. Will Roach
U.S. Fish and Wildlife Service
Division of Ecological Services
Houston, Texas

The stress protein response is a promising, new biomarker of pollutant exposure and effect in estuarine invertebrates and fish. Stress proteins are a group of proteins whose synthesis is induced in response to specific environmental stressors, such as heat shock (Sanders, 1990), or chemical stressors, such as metals, organic compounds and pesticides (Steinert et al., 1991; Dyer et al., 1991; Howard et al., 1991). Stress proteins are found in all eukaryotes and it is believed that many of them play roles either in protecting cells from damage that results from stress or in restoring function to damaged cells (Stegeman et al., 1992).

The goal of our research is to determine whether the stress protein response in estuarine invertebrates and fish is the manifestation of sublethal toxicity or an adaptive response to pollution exposure. Both have implications for the Galveston Bay estuarine community as they affect the longevity, population structure, and/or reproduction of the resident organisms. The present study incorporates laboratory and field approaches in the investigation of the relationship between contaminant-specific stress protein (CSSP) accumulation in grass shrimp (*Palaemonetes pugio*) and pollution tolerance in the natural environment.

The objectives of the laboratory study were to identify and quantify contaminant-specific stress proteins (CSSPs) in grass shrimp exposed to sediment from a produced water discharge site, then determine significant correlations between CSSP accumulation and the chemical components of the sediment. Sediment was collected from three stations along a transect extending from a shoreline produced water discharge outfall in Tabbs Bay and from a reference site in upper Galveston Bay (Fig. 1). Sediment samples were analyzed for aliphatic and polycyclic aromatic hydrocarbon compounds and metals. Lab-acclimated grass shrimp were exposed to test or reference sediment in either resuspended sediment (96 h) or solid phase benthic (10 d) tests (modified from U.S. EPA, 1990). CSSPs of test survivors were identified by their apparent molecular weights on 10 percent SDS gels and were quantified by scanning densitometry.

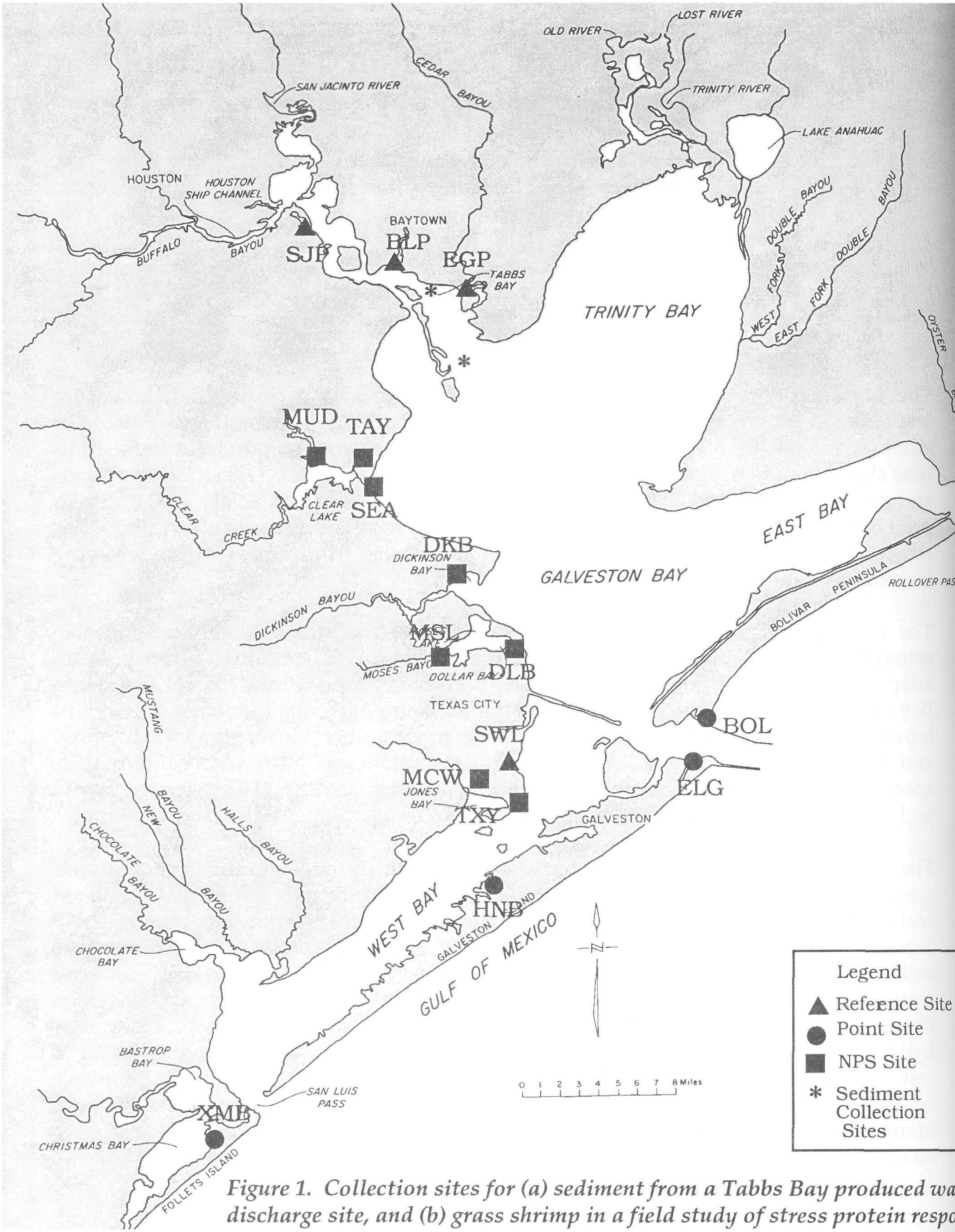

Figure 1. Collection sites for (a) sediment from a Tabbs Bay produced water discharge site, and (b) grass shrimp in a field study of stress protein response

Table 1. Classification of sites in Galveston Bay selected for the field study of stress protein response in grass shrimp (Palaemonetes pugio).

Class[1]	*Site*	*Type of contamination* *Industrial*	*Petrochemical*	*Metal*
R	XMB Christmas Bay			
R	BOL Bolivar Flats			
R	ELG East Lagoon			
R	HNB Hance Bayou			
P	SJP San Jacinto Pk	x	x	
P	SWL Swan Lake	x		x
P	EGP Evergreen Point		x	x
P	BLP Bayland Park	x	x	x
N	TXY Texas City Wye	x	x	
N	DKB Dickinson Bay	x	x	x
N	DLB Dollar Bay		x	x
N	MSL Moses Lake		x	x
N	TAY Taylor Lake	x	x	x
N	MTW Motco West	x	x	
N	SEA Seabrook Slough	?	?	
N	MUD Mud Lake	?	?	
N	GIL Gilchrist		?	

[1] R = Reference, P = Point source, N = Non-point source

Table 2. Significant Pearson product-moment correlations between sediment contaminants associated with produced water and contaminant-specific stress protein (CSSP) accumulation in grass shrimp (Palaemonetes pugio).

CSSP	*Exposure medium*	*Correlations ($p<0.05$)* *Positive*	*Negative*
51 kD	Solid phase sediment	Metals	—
	Resuspended sediment	—	—
31 kD	Solid phase sediment	—	Aliphatics
	Resuspended sediment	PAHs Oil & grease	Aliphatics
64 kD	Solid phase sediment	Aliphatics	Metals
	Resuspended sediment	PAHs Oil & grease Aliphatics	—

The objectives of the field study were to compare ambient CSSP levels in grass shrimp in their natural environments and then relate differences in CSSP accumulation in these shrimp to their tolerance under laboratory cadmium exposure conditions. Grass shrimp were collected from 17 sites in Galveston Bay (Fig. 1) that varied in the type and extent of sediment contamination (Table 1). Shrimp from each site were randomly divided into ambient (frozen immediately upon collection) or cadmium challenge groups (0, 0.5 or 1.0 mg Cd^{2+}/l for 96 h). CSSPs were again identified by SDS gel electrophoresis and quantified by scanning densitometry.

In the laboratory study, three CSSPs in grass shrimp correlated significantly with the chemical components of brine-contaminated sediment (Table 2). A 51 kD protein was accumulated in response to exposure to metals, including aluminum, arsenic, chromium, copper, iron, nickel, lead, and zinc. Accumulation of 31 kD and 64 kD proteins was associated with exposure to certain polycyclic aromatic hydrocarbon compounds, and the 64 kD protein was also accumulated in shrimp exposed to high levels of aliphatic hydrocarbons. There were also significant differences in CSSP accumulation associated with the sediment test phase (solid phase vs resuspended).

In the field study, the 51 kD protein was accumulated in grass shrimp collected from the polluted sites that were subsequently exposed to the cadmium challenge tests in the laboratory. In addition, a 20 kD protein was found at significantly higher ambient levels in grass shrimp collected from polluted sites compared to shrimp collected from reference sites. This protein was also accumulated under cadmium exposure conditions in the laboratory tests; however, as with the 51 kD protein, the 20 kD protein was accumulated only in shrimp that had been collected from the polluted sites. Grass shrimp accumulating the highest levels of the 20 kD protein also exhibited the greatest tolerance (measured as survival) to the cadmium challenge.

These results suggest that the 20 kD and 51 kD CSSPs may be part of an adaptive response of estuarine organisms to contaminants in their habitats. As such, the stress protein response can serve as a sensitive biomarker of sublethal pollutant exposure and effect. Such information can be useful to the Galveston Bay National Estuary Program in its Comprehensive Conservation and Management Plan for coastal managers.

Bibliography

Dyer, S.D., S.M. Covington, K.L. Dickson, and E.G. Zimmerman. 1991. Stress protein responses of fish exposed to lindane and diazinon. SETAC 12th annula meeting, Abstr. 479, Seattle, WA.

Howard, C.L., K.R. Whitt, and R.W. Roach. 1991. Quantification of stress proteins in grass shrimp exposed to contaminated estuarine sediment. SETAC 12th annual meeting, Abstr. 480, Seattle, WA.

Sanders, B. 1990. Stress proteins: potential as multitiered biomarkers. Pages 165-191 in J.F. McCarthy and L.R. Shugart, eds. Biomarkers of environmental contamination. Lewis Publishers, Boca Raton, FL.

Stegeman, J.J., M. Brouwer, R.T. DiGiulio, L. Forlin, B.A. Fowler, B.M. Sanders, and P.A. VanVeld. 1992. Enzyme and protein synthesis as indicators of contaminant exposure and effect. Pages 235-335 in R.J. Huggett, R.A. Kimmerle, P.M. Mehrle, Jr. and H.L. Bergman, eds. Biomarkers: biochemical, physiological, and histological markers of anthropogenic stress. Lewis Publishers, Boca Raton, FL.

Steinert, S.A., S. Cormier, J. Amstutz, and G.V. Pickwell. 1991. Expression of SP70 proteins in *Mytilus edulis* and *Ictalurus nebulosus*. SETAC 12th annual meeting, Abstr. 481, Seattle, WA.

U.S. Environmental Protection Agency. 1990. Draft ecological evaluation of proposed discharge of dredged material into ocean waters. EPA-503-8-90/002.