Characterization of Potential Adverse Health Effects Associated with Consuming Fish or Blue Crab from

Trinity Bay and Upper Galveston Bay

Chambers, Galveston, and Harris Counties, Texas

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INTRODUCTION

Description of the Galveston Bay System

Galveston Bay, the largest estuary on the Texas coast (600 square miles or 384,000 acres; 232 miles of shoreline) and the seventh largest in the United States, is a shallow bar-built estuary in a drowned river delta.[1] The average depth of the bay is 7 feet, the maximum non-dredged depth approximately 10 feet.[2] Galveston Bay is composed of four major sub-bays: Galveston Bay, Trinity Bay, East Bay, and West Bay.[3] The Galveston Bay watershed encompasses approximately 33,000 square miles comprised of three main drainages: the Trinity River watershed, the San Jacinto River watershed, and the coastal bayou watershed. The Trinity River basin provides about 51% of the freshwater inflow into Galveston Bay.[3]

The Galveston Bay watershed includes all or portions of 44 Texas counties; five counties surround the estuary: Brazoria, Chambers, Galveston, Harris, and Liberty. The watershed also includes the two largest metropolitan areas in Texas: Houston and Dallas–Fort Worth.[2] To lend perspective to the size of this watershed, note that the city of Houston lies approximately 250 miles south-southeast of Dallas-Fort Worth.

Galveston Bay, Texas' largest fishery resource, contributes approximately one third of the state's commercial fishing income.[4] Commercial and recreational fishing on Galveston Bay generates over one billion dollars per year; over one-half of the state's expenditures for recreational fishing go directly or indirectly to Galveston Bay.[4] The areas around the Galveston Bay system are also home to one of the nation's largest petrochemical and industrial complexes[5]. Nearly half of all U.S. petrochemical production occurs in the greater Houston area. The Port of Houston is the second largest port (by tonnage shipment) in the nation, and is the eighth largest in the world.[6] As a result, industrial and municipal point source discharges contribute to the bay's major pollution. Still, non-point source pollution remains the bay's top water quality problem, with much originating from storm water runoff generated by agricultural, urban, suburban, and rural land users near the bay. Some 90% of the oil and grease loading, for instance, originate in sub-watersheds with high-density urban land use. Much of the oil and grease flows from the surfaces of roadways.[7]

Demographics of the Five Texas Counties (Brazoria, Chambers, Galveston, Harris, and Liberty) Surrounding the Galveston Bay Estuary System

The estimated population in 2006 of the five counties bordering the Galveston Bay system – Brazoria (287,898), Chambers (28,779), Galveston (283,551), Harris (3,826,207), and Liberty (75,685) – was 4,502,120 people.[8] The Galveston Bay system is adjacent to one of the most urbanized and industrialized areas in Texas and in the United States. In comparison to suburban communities in the five-county area, the larger central cities, such as Houston, TX (2006 estimated population 2,144,491)[9] – the fourth largest city in the United States and the Harris County seat – and Galveston (2003 estimated population 56,667)[10] experienced little or no population growth during the recent past. According to the United States Census Bureau, Harris County is the most populous in Texas. The Houston-Galveston Area Council calculated that 70 % of the Galveston County population and almost 45% of the Chambers County population (or approximately 20 % of the 4.5 million people in the five counties bordering Galveston Bay) reside within a two-mile buffer zone around Galveston Bay and its tidally influenced tributaries.[3]

Subsistence Fishing in the Galveston Bay System

The United States Environmental Protection Agency (USEPA) suggests that, besides the ethnic characteristics and the varied cultural practices of an area's population, the poverty rate could influence the area's rate of subsistence fishing.[11] The USEPA and the Department of State Health Services (DSHS)[a] believe it important to consider subsistence fishing to occur around any Texas water body precisely because subsistence fishers – along with recreational anglers and certain tribal and ethnic groups – likely consume more locally caught fish than does the general population. These groups sometimes harvest fish or shellfish from the same water body for many years to supplement caloric and protein intake. Because of these practices, such groups may routinely eat chemically contaminated fish or shellfish from a water body or may periodically eat large quantities of contaminated fish from the same waters, consumption habits that could increase their risk of adverse health effects from consumption of self-collected fish or shellfish. The USEPA suggests the states assume that at least 10% of licensed fishers in any area will be subsistence fishers.[11] The number of unlicensed fishers in an area is difficult to determine, but it is reasonable to expect that many such peoples would also be subsistence fishers. Although the DSHS has not explicitly documented subsistence fishing in the areas covered in this report, anecdotal information suggests subsistence fishing is likely. Because of the difficulty of determining directly the number of subsistence fishers in any given area, the DSHS – in accordance with USEPA guidance[11] – uses a factor of 10% of *licensed* fishers to estimate the number of subsistence fishers in local areas of the state.

History of DSHS Monitoring of Chemical Contaminants in Fish and Shellfish from the Galveston Bay Estuary System

The USEPA's *National Dioxin Study* [12] was a nationwide investigation of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8 TCDD) contamination of soil, water, sediment, air, and fish). In 1986, as a part of the National Study of Chemical Residues in Fish (NSCRF - formerly the *National Bioaccumulation Study*) [13] that grew out of the USEPA's *National Dioxin Study,* the United States Environmental Protection Agency (USEPA) conducted a one-time nationwide survey of contaminant residues in fish. In that evaluation of fish-borne contaminants, the USEPA reported the presence of dioxin congeners in samples of fish and some shellfish (e.g., blue crab) from 11 sites within its Region 6. These sites were almost invariably located downstream of "bleach kraft" pulp and paper mill discharges.

In 1990, the DSHS – in its first in-depth evaluation of Texas sites reported by the *National Dioxin Study* [12] to harbor dioxin-contaminated fish or shellfish – collected 12 fish and composite blue crab samples from the Houston Ship Channel and from Upper Galveston Bay. The 1990 DSHS study confirmed polychlorinated dibenzofurans (PCDFs) and polychlorinated dibenzo-p-dioxins (PCDDs) in catfish species and blue crab at concentrations that could pose a risk to human health. As a result, the DSHS issued Advisory #3 (ADV-3), a consumption advisory for Upper Galveston Bay. The advisory covered Upper Galveston Bay north of a line connecting Red Bluff Point to Houston Point by way of the Five Mile Cut marker, along with the Houston Ship Channel and its contiguous waters. ADV-3 recommended that adult recreational and/or subsistence fishers limit consumption of catfish and/or blue crab to no more than one eight-ounce

[a] *Formerly the Texas Department of Health (TDH)*

meal per month. In addition, the DSHS advised that children whose age is less than 12 years and women of childbearing age not consume catfish or blue crab from these waters.[14] Furthermore, fish and blue crab samples collected in 1993 from Clear Creek contained several volatile organic compounds – including dichloroethane and trichloroethane at concentrations that, if consumed, constituted an apparent risk to public health. To address the public health hazard introduced by consumption of fish and blue crab from Clear Creek – which empties into Upper Galveston Bay – the DSHS issued Advisory #7 (ADV-7) on November 18, 1993. ADV-7 recommended that persons should not consume fish or blue crab from Clear Creek upstream and West of Texas Highway 3.[14]

In 1994, through its *Near Coastal Water Grant (NCWG),* the USEPA granted the DSHS funding to investigate chemical contaminants in fish and shellfish from four locations along the Texas coast. As part of the *NCWG* study, the DSHS collected and analyzed five samples from the Houston Ship Channel and Upper Galveston Bay for PCDFs/PCDDs. Results from the NCWG study showed what might have been a slight decrease in average dioxin concentrations in catfish, blue crab, and oysters when compared to the 1990 data. However, the small number of samples limited conclusions, and made it impossible for the DSHS to reassess the health risks from consumption of fish, blue crab, or oysters from the Houston Ship Channel and Upper Galveston Bay or to revise risk management decisions for the area. Consequently, the DSHS continued unchanged ADV-3, the consumption advisory issued in 1990 for these areas.

In 1996, the DSHS collected 10 fish, four composite oyster samples, and 10 composite blue crab samples from the Houston Ship Channel and Upper Galveston Bay to re-evaluate ADV-3, the aforementioned 1990 consumption advisory. The results of the 1996 study also suggested that the 1990 advisory limiting consumption of catfish and blue crab should continue unchanged. Again, the DSHS continued ADV-3 in its original form.

The USEPA funded three grants between 1997 and 2000 for study of the Galveston Bay system. These grants: (1) "The USEPA Children's Uses of Galveston Bay" grant; (2) another EPA grant – this one administered by the Texas Commission on Environmental Quality (TCEQ)[b] Total Maximum Daily Load (TMDL) program; and (3) a grant funded through the Galveston Bay Estuary Program (GBEP)[15] – allowed the DSHS to complete a comprehensive evaluation of chemical contaminants in fish and shellfish from the estuary system. For this study, the DSHS collected more than 400 fish and blue crab samples from East and West Galveston Bay, Lower Galveston Bay, Trinity Bay, Upper Galveston Bay, and the Houston Ship Channel (including the Lower San Jacinto River and Tabbs Bay). In addition to these major bay areas, the DSHS also surveyed the Christmas Bay system (Bastrop, Christmas, and Drum Bays), Clear Creek (for which ADV-7 was issued in 1993), and Clear Lake.

The Galveston Bay studies conducted between 1997 and 2000 revealed that – with few exceptions – contaminants in fish and blue crab from the Christmas Bay system, East Bay and West Bay, Lower Galveston Bay, Trinity Bay, Clear Creek, and Clear Lake no longer exceeded the DSHS health-based assessment comparison values (HAC values) for adverse human health effects from myriad chemical contaminants. The DSHS thus concluded that eating fish and blue crab from these portions of the Galveston Bay system posed no apparent public health hazard. Furthermore, on October 9, 2001, as a direct result of the 1997-2000 studies showing that

[b] *Formerly the Texas Natural Resource Conservation Commission (TNRCC)*

consumption of fish and shellfish from Clear Creek no longer posed a risk to human health, the DSHS rescinded ADV-7, issued in 1993 on all fish and blue crab from Clear Creek.[16]

On the other hand, the 1997-2000 studies yielded other data that prompted the DSHS to modify ADV-3 with Advisory 20 (ADV-20). ADV-20 extended ADV-3 to recommend limited consumption of blue crab and all fish from the upper Houston Ship Channel (including the Lower San Jacinto River). ADV-20 recommended that adults eat no more than one eight-ounce meal per month of any species of fish or of blue crab from the Houston Ship Channel upstream of the Lynchburg Ferry crossing or from the San Jacinto River downstream of the bridge at U.S. Highway 90. ADV-20 further stressed that children and women who were nursing an infant, who were pregnant, or who might become pregnant should eat no fish or blue crab from the above-described areas.[17]

In 1987, the U.S. Congress established the National Estuary Program (NEP) to promote long-term planning and management of nationally significant estuaries.[18] The NEP identified 28 nationally significant estuaries, of which Galveston Bay was one (the second in Texas is the Coastal Bend Bays and Estuaries). The Galveston Bay Estuary Program (GBEP), established in 1989, is one of two such programs in Texas.[19] The GBEP is a non-regulatory program administered by the Texas Commission on Environmental Quality. Working with local governments, businesses, ports, commercial fisheries, recreational anglers, environmental organizations, and state and federal natural resource agencies, the GBEP implements the Galveston Bay Plan (GBP), a comprehensive conservation management plan for Galveston Bay.[15] The GBEP provides ecosystem management through collaborative partnerships and ensures preservation of Galveston Bay's multiple uses. Among the accomplishments of the GBEP are enhanced water quality through promotion of reduction of pollutants in bayous, creeks, and Galveston Bay, and establishment of a seafood-safety monitoring program to protect the health of those who consume fish and shellfish from the Galveston Bay Estuary system.[19]

In 2003-2004, the GBEP received a grant from the USEPA under Section 104(b)(3) of the Clean Water Act. That grant provided funds to demonstrate implementation of Action PH-1: "Develop a Seafood Consumption Safety Program for the *Galveston Bay Plan*." This project was the first phase of the Seafood Consumption Safety Monitoring Program for Galveston Bay, a project that evaluated the following areas of the Galveston Bay System: Upper Galveston Bay near LaPorte, TX, the Houston Ship Channel, and the Lower San Jacinto River. The objectives of the Seafood Consumption Safety Monitoring Program, as set forth in the *Galveston Bay Plan,* are to regularly characterize and monitor potential health risks associated with consumption of seafood from the Galveston Bay system and to inform the public of seafood consumption risks identified by the study.

The results of the 2004 risk assessment of fish and blue crab tissue from the study area showed unequivocally that ADV-3, issued in 1990 and modified with ADV-20 in 2001 should continue. The results also revealed that spotted seatrout contained polychlorinated biphenyls (PCBs) at levels that exceeding the DSHS' HAC values for PCBs in fish. The presence of PCBs in spotted seatrout at the observed levels caused concern among public health officials. The DSHS thus issued a fish consumption advisory modification (ADV-28) for the Houston Ship Channel and Upper Galveston Bay. ADV-28 recommends that adults limit consumption of spotted seatrout from the Houston Ship Channel – including the tidal portion of the San Jacinto River below the U.S. Highway 90 bridge, Tabbs Bay and all contiguous waters, and Upper Galveston Bay north of a line drawn from Red Bluff Point to Five Mile Cut Marker to Houston Point – to no more than one eight-ounce meal per month. Children and women who are nursing, pregnant – or who may become pregnant – should not consume spotted seatrout from these waters.[20]

The 2004 risk characterization also recommended additional fish tissue monitoring to determine whether spotted seatrout throughout the Galveston Bay system contain PCBs at concentrations of concern to public health. Texas Parks and Wildlife Department (TPWD) tagging data indicate that spotted seatrout tend to move throughout the entire Galveston Bay system. Spotted seatrout are a top predator fish found throughout the entire United States gulf coast waters. The species is one of the most sought after sport fishes along the Texas coast. Because spotted seatrout are a primary target for recreational anglers, determining the extent of PCB contamination has public health, regulatory, and economic implications for the Galveston Bay complex.

The present report summarizes the 2006 evaluation of fish and blue crab from Trinity Bay and Upper Galveston Bay (south of Five Mile Cut Marker and north of a line drawn from Eagle Point to Smith Point). The study examined the extent of contamination of spotted seatrout in the Galveston Bay system and evaluated progress in developing a routine seafood-monitoring program for Galveston Bay as a component of the *Galveston Bay Plan.* This report addresses the public health implications of consuming contaminated fish and/or blue crab from the bays. The report further outlines progress in development of the routine seafood-monitoring program mandated by the *Galveston Bay Plan*.

METHODS

Fish Sampling, Preparation, and Analysis

The Department of State Health Services Seafood and Aquatic Life Group (DSHS SALG) collects and analyzes edible portions of fish and shellfish from the state's public waters to evaluate potential risks to the health of people who consume contaminated fish or shellfish. Fish tissue sampling follows standard operating procedures from the DSHS *Seafood and Aquatic Life Group Survey Team Standard Operating Procedures and Quality Control/Assurance Manual.*[21] The SALG bases its sampling and analysis protocols, in part, on procedures recommended by the USEPA in that agency's *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1.*[22] Advice and direction are also received from the legislatively mandated *State of Texas Toxic Substances Coordinating Committee (TSCC) Fish Sampling Advisory Subcommittee (FSAS).*[23] Samples usually represent species, trophic levels, and legal-sized specimens available for consumption from the water body(s) under investigation. When practical, the DSHS collects samples from two or more sites within a water body to better characterize geographical distributions of contaminants in fish.

Fish Sampling Methods and Description of the 2006 Trinity Bay and Upper Galveston Bay Sample Set

Between April and June 2006, SALG staff collected 110 fish and 12 composite blue crab samples from Trinity Bay and Upper Galveston Bay. Risk assessors used data from these fish to assess the potential for adverse human health outcomes from consuming fish from these bays.

The SALG selected six sites to provide spatial coverage of the study area (Figure 1). Site 1 was located near Pine Gully, Site 2 near the Clifton Beach, Site 3 near Lone Oak Bayou, Site 4 near the mouth of the Trinity River, Site 5 at the Houston Light and Power (HL&P) outfall, and Site 6 near Umbrella Point. Species collected represent distinct ecological groups (e.g., predators and bottom-dwellers) that have some potential to bio-accumulate chemical contaminants, have a wide geographic distribution, are of local recreational fishing value, and/or that anglers commonly consume. The 110 fish and 12 composite blue crab samples collected from Trinity Bay and Upper Galveston Bay during the April-June 2006 sampling period represented all targeted species. Table 1 lists the species and numbers collected from each site: black drum (8), blue crab (12), gaftopsail catfish (17), red drum (7), southern flounder (7), and spotted seatrout (71).

The survey team set gill nets and blue crab traps at each of the sampling sites in late afternoon, fished the sites overnight, and collected samples from the nets early the following morning. Gill nets maximized available cover and habitat in the bay. As bait for the blue crab traps, the SALG survey team used “rough” fish collected from the first gill nets deployed. The survey team stored captured fish and blue crab retrieved from the nets and traps on wet ice until processed. During collection, to keep specimens from different sample sites separated, the team placed samples from each site into mesh bags labeled with the site number. Team members returned to the bay any live fish or blue crab culled from the catch and properly disposed of samples found dead in the gill nets or crab traps.

Collecting spotted seatrout with gill nets proved a difficult task; spotted seatrout gill net catch rate averaged 0.5 spotted seatrout per net per night. The gill nets generally captured only hardhead catfish, gaftopsail catfish, bull shark, black drum, stingrays, and menhaden. To increase the spotted seatrout catch-rate, the team switched to a hook and line technique, targeted habitats likely to harbor spotted seatrout (e.g., oyster reefs, oil and gas rigs, bayou cuts, piers, pilings, channel breaks, areas underneath feeding birds, and power plant discharge points), and used artificial baits and live shrimp. Survey team members fished these habitats with the boat anchored near the above-itemized structures or drifting with the wind or tide. Catch success of spotted seatrout was best near Site 5 – the Houston Lighting and Power (HL&P) outfall.

The team processed all fish and blue crab samples at the SALG regional office in Bacliff, TX, using an electronic scale to weigh fish samples to the nearest gram. Staff also measured the total length of each fish (tip of nose to tip of tail fin) to the nearest millimeter. Using a filleting knife, staff recovered two skin-off fillets from each fish sample. Blue crab carapace width was also measured to the nearest millimeter (individual blue crab samples were not weighed). SALG staff worked from an aluminum foil-wrapped cutting board, removing the top shell from each blue crab specimen to expose the body cavity and eviscerating the specimen by removing the feathery gills just proximal to the legs, along with all loose viscera, mouthparts, and eggs. After thoroughly rinsing the body cavity with distilled water, survey staff combined four to eight eviscerated whole blue crab samples to produce each composite blue crab sample.

To ensure that cross-sample contamination did not occur, team members changed the cutting board foil and rinsed the fillet knife with distilled water between each sample (whether crab or fish). Wrapping each in two layers of clean aluminum foil, team members placed each sample into a separate, unused, pre-labeled plastic freezer bag, subsequently storing all samples in the regional office’s chest freezer. At the end of the sampling trip, the survey team transported the prepared samples on wet ice to headquarters in Austin, TX, temporarily storing them at -5° Fahrenheit (-20° Celsius) in a secure freezer. To ensure an intact chain of custody, the freezer key is accessible only to authorized SALG staff.

During the week following each collection trip, the survey team shipped frozen tissue samples by commercial carrier (UPS Next-Day Air®) to the Geochemical and Environmental Research Group (GERG) laboratory at Texas A&M University in College Station, TX, for contaminant analyses.

Analytical Laboratory Information

Upon their arrival at the GERG laboratory, GERG personnel notified the SALG of receipt of the 122 Upper Galveston Bay-Trinity Bay samples and recorded the condition of each sample along with its DSHS identification number.

Using established EPA methods, the GERG laboratory analyzed fish fillets and composite blue crab tissues from Trinity Bay and Upper Galveston Bay for inorganic and organic contaminants commonly identified in polluted environmental media; analyses included seven metals (arsenic, cadmium, copper, lead, total mercury, selenium, and zinc), 123 semivolatile organic compounds (SVOCs), 71 volatile organic compounds (VOCs), 34 pesticides, 209 PCB congeners, and 17 congeners of polychlorinated dibenzofurans and/or dibenzo-*p*- dioxins (PCDFs/PCDDs). The laboratory analyzed all 122 samples only for pesticides and PCBs. The laboratory analyzed subsets of the original 122 samples for other contaminants: 55 for metals and PCDFs/PCDDs, and 14 for SVOCs and VOCs.[24]

Specific Details of Some Analyses with Explanatory Notes

Arsenic

The GERG laboratory analyzed fish and blue crab samples for total arsenic (inorganic arsenic + organic arsenic = total arsenic) because the analytical literature on arsenic in fish suggests that, in general, well over 90% is organic arsenic – a form of arsenic that is virtually non-toxic to humans.[25] Although the proportion of inorganic to organic arsenic may differ among species, under different water conditions, and, perhaps, with other variables, the DSHS SALG risk assessors conservatively assume that at least 10% of the arsenic in any fish is inorganic arsenic. The SALG risk assessors thus multiply laboratory-determined total arsenic concentration in each fish by a factor of 0.10 to determine probable inorganic arsenic concentration in that sample.[25] After determining inorganic arsenic concentration in individual samples, risk assessors calculate the average concentration of inorganic arsenic in groups of interest.

Mercury

Nearly all mercury in upper trophic level fish three years of age or older is methylmercury.[26] Thus, total mercury concentration in a fish of legal size for possession in Texas serves well as a surrogate for methylmercury concentration in a fish. Historically, methylmercury analysis is difficult to perform accurately and is more expensive to run than is analysis of total mercury. The USEPA, therefore, recommends that states determine total mercury in fish. To protect human health, however, the USEPA also advises states to assume that 100% of the mercury measured in each fish or shellfish is methylmercury. Therefore, the GERG laboratory analyzed fish and blue crab tissues for total mercury. Following USEPA guidance, the DSHS compares total mercury concentrations to a comparison value derived from the ATSDR's minimal risk level for methylmercury toxicity[27] (in these risk summaries, the DSHS may interchangeably utilize the terms "mercury," "methylmercury," or "organic mercury" to refer to methylmercury in fish).

Polychlorinated Biphenyls (PCBs)

For PCBs, the USEPA suggests that each state measures congeners of PCBs in fish and shellfish rather than homologs or Aroclors® because that agency considers congener analysis the most sensitive technique for detecting PCBs in environmental media.[24] Although only about 130 PCB congeners were routinely present in PCB mixtures manufactured and commonly used in the U.S., the GERG laboratory analyzes and reports the presence and concentrations of all 209 possible PCB congeners. From the congener analyses, the laboratory also computes and reports concentrations of PCB homologs and of Aroclor® mixtures.

Despite EPA's suggestion that the states utilize PCB congeners rather than Aroclors® or homologs for toxicity estimates, the toxicity literature does not reflect state-of-the-art laboratory science. To accommodate this inconsistency, the DSHS utilizes recommendations from the National Oceanic and Atmospheric Administration (NOAA),[28] from McFarland and Clarke,[29] and from the USEPA's guidance documents for assessing contaminants in fish and shellfish[22, 24] to address PCB congeners in fish and shellfish samples. The preceding references recommend using 43 congeners for their likelihood of occurrence in fish, the likelihood of significant toxicity – based on structure-activity relationships – and for the relative environmental abundance of the congeners. [28, 29] SALG risk assessors sum the 43 suggested congeners to derive a "total" PCB concentration in each sample. Assessors then average the summed congeners within each group (e.g., species, site, or combination of site and species) to derive a mean PCB concentration for groups of interest.

Using only a few PCB congeners to determine total PCB concentrations could conceivably underestimate PCB levels in fish tissue. Nonetheless, the method complies with expert recommendations on evaluation of PCBs in fish or shellfish. Therefore, SALG risk assessors compare average PCB concentrations of the 43 congeners with HAC values derived from information on PCB mixtures held in the USEPA's Integrated Risk Information System (IRIS) database.[30] IRIS currently contains systemic toxicity information for five Aroclor® mixtures: Aroclors® 1016, 1242, 1248, 1254, and 1260 (not all information is available for all mixtures; for instance, only one other RfD occurs in IRIS – that of Aroclor 1016, a commercial mixture devoid of dibenzofurans).[31] Systemic toxicity estimates in the present document reflect comparisons derived from the USEPA's reference dose (RfD) for Aroclor 1254. As of yet, IRIS does not contain information on the systemic toxicity of individual PCB congeners.

For assessment of cancer risk from exposure to PCBs, the SALG uses the USEPA's highest slope factor of 2.0 per (mg/kg/day) to calculate the probability of lifetime excess cancer risk from PCB ingestion. The SALG based its decision to use the most restrictive slope factor available for PCBs on factors such as food chain exposure, the presence of dioxin-like, tumor-promoting, or persistent congeners, and the likelihood of early-life exposure.[32]

Statistical Analysis of Analytical Data

The SALG risk assessors imported Excel© files into SPSS® statistical software, version 13.0 installed on IBM-compatible microcomputers (Dell, Inc) and used SPSS® to generate descriptive statistics (mean, standard deviation, median, minimum and maximum concentrations, and range) on measured compounds in each species from each sample site.[33] In computing descriptive statistics, SALG risk assessors have previously utilized ½ the detection limit for analytes designated as not detected (ND) or estimated (J)[c] In the present evaluation of PCDF/PCDD computations, the SALG employed estimated J concentrations as reported and assumed that values designated "ND" were zero to avoid inflating PCDF/PCDD concentrations. The SALG used the descriptive statistics from the above manipulations to generate the present report. The SALG protocols do not require hypothesis testing. Nevertheless, when data are of sufficient quantity and quality, and, should it be necessary, the SALG can utilize SPSS® software to determine significant differences among contaminant concentrations in species and/or at collection sites as needed. The SALG employed Microsoft Excel® spreadsheets to generate figures, to compute health-based assessment comparison values (HAC_{nonca} and HAC_{ca}) for contaminants, and to calculate hazard quotients (HQ), hazard indices (HI), cancer risk probabilities, and meal consumption limits for fish or shellfish from Trinity Bay and Upper Galveston Bay.[34] When lead concentrations in fish or shellfish are high, SALG risk assessors may utilize the USEPA's Interactive Environmental Uptake Bio-Kinetic (IEUBK) model to determine whether consumption of lead-contaminated fish could cause a child's blood lead (PbB) level to exceed the Centers for Disease Control and Prevention's (CDC) lead concentration of concern in children's blood (10 mcg/dL).[35, 36]

Calculation of Toxicity Equivalent Quotients (TEQs) for Dioxins

Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDDs/PCDFs) are families of aromatic chemicals containing one to eight chlorine atoms. The molecular structures differ not only with respect to the number of chlorines on the molecule, but also with the positions of those chlorines on the carbons atoms of the molecule. The number and positions of the chlorines on the dibenzofuran or dibenzo-*p*-dioxin nucleus directly affects the toxicity of the various congeners. Toxicity increases as the number of chlorines increases to four chlorines, then decreases with increasing numbers of chlorine atoms - up to a maximum of eight. With respect to the position of chlorines on the dibenzo-*p*-dioxin/dibenzofuran nucleus, it appears that those congeners with chlorine substitutions in the 2, 3, 7, and 8 positions are more toxic than congeners with chlorine substitutions in other positions. To illustrate, the most toxic of PCDDs is 2,3,7,8–tetrachlorodibenzo-*p*-dioxin (2,3,7,8–TCDD), a 4-chlorine molecule having one chlorine substituted for hydrogen at each of the 2, 3, 7, and 8 carbon positions on the dibenzo-*p*-dioxin. To gain some measure of toxic equivalence, 2,3,7,8–TCDD – assigned a toxicity equivalency factor (TEF) of 1.0 – is the standard against which other congeners are measured. Other congeners are given weighting factors or TEFs of 1.0 or less based on experiments comparing the toxicity of the congener relative to that of 2,3,7,8-TCDD.[37, 38]

[c] *"J-value" is standard laboratory nomenclature for analyte concentrations that are detected and reported below the method detection limit (<MDL). The reported concentration is considered an estimate, quantitation of which may be suspect and may not be reproducible. The DSHS treats J-Values as "not detected" in its statistical analyses of a sample set.*

Using this technique, risk assessors from the DSHS converted PCDF or PCDD congeners in each tissue sample from the present survey to toxicity equivalents (TEQs) by multiplying each congener's concentration by its TEF, producing a dose roughly equivalent in toxicity to that of the same dose of 2,3,7,8-TCDD. The total TEQ for any sample is the sum of the TEQs for each of the congeners in the sample, calculated according to the following formula.[39]

$$\text{Total TEQs} = \sum_{i=1}^{n} (CI \times TEF)$$

CI = concentration of a given congener
TEF = toxicity equivalence factor for the given congener
n = # of congeners
i = initial congener
? = sum

Derivation and Application of Health-Based Assessment Comparison Values (HAC_{nonca}) for Systemic (noncarcinogenic) Effects of Consumed Chemical Contaminants)

The effects of exposure to any hazardous substance depend, among other factors, on the dose, the route of exposure, the duration of exposure, the manner in which the exposure occurs, the genetic makeup, personal traits, and habits of the exposed, and the presence of other chemicals.[40] People who regularly consume contaminated fish or shellfish conceivably suffer repeated low-dose exposures to contaminants in fish or shellfish over extended periods (episodic exposures to low doses). Such exposures are unlikely to result in acute toxicity but may increase risk of subtle, chronic, and/or delayed adverse health effects that include cancer, benign tumors, birth defects, infertility, blood disorders, brain damage, peripheral nerve damage, lung disease, and kidney disease, to name but a few.[40] If diverse species of fish or shellfish is available, the SALG presumes that people eat a variety of species from a water body. Further, SALG risk assessors at DSHS assume that most fish species are mobile. SALG risk assessors may combine data from different fish species, blue crab, and/or sampling sites within a water body to evaluate mean contaminant concentrations of toxicants in all samples as a whole. This approach intuitively reflects consumers' likely exposure over time to contaminants in fish or shellfish from any water body, but may not reflect the reality of exposure at a specific water body or a single point in time. The DSHS reserves the right to project risks associated with ingestion of individual species of fish or shellfish from separate collection sites within a water body or at higher than average concentrations (e.g. the upper 95 percent confidence limit on the mean). The SALG derives confidence intervals from Monte Carlo simulations using software developed by Richard Beauchamp, MD, a DSHS medical epidemiologist.[41] The group evaluates contaminants in fish or shellfish by comparing the mean or the 95% upper confidence limit on the average concentration of a contaminant to its HAC value (in mg/kg) for non-cancer or cancer endpoints.

In deriving HAC values for systemic (HAC_{nonca}) effects, the SALG assumes a standard adult weighs 70 kilograms and consumes 30 grams of fish or shellfish per day (about one 8-ounce meal per week) and uses the USEPA's oral reference dose (RfD)[42] or the Agency for Toxic Substances and Disease Registry's (ATSDR) chronic oral minimal risk levels (MRLs).[43] The USEPA defines an RfD as

> *An estimate of a daily oral exposure for a given duration to the human population (including susceptible subgroups) that is likely to be without an appreciable risk of adverse health effects over a lifetime.*[44]

The USEPA also states that the RfD

> *… is derived from a BMDL* (benchmark dose lower confidence limit)*, a NOAEL* (no observed adverse effect level)*, a LOAEL* (lowest observed adverse effect level)*, or another suitable point of departure, with uncertainty/variability factors applied to reflect limitations of the data used. [Durations include acute, short-term, subchronic, and chronic and are defined individually in this glossary]* and *RfDs are generally reserved for health effects thought to have a threshold or a low dose limit for producing effects.*[44]

The ATSDR uses a similar technique to derive its MRLs.[43] The DSHS compares the estimated daily dose (calculated in mg/kg/day as: Dose (mg/kg/day) = concentration of toxicant in sample (mg/kg) *daily consumption (kg/day)/body weight (kg) – derived from the mean of the measured concentrations of a contaminant – to the contaminant's RfD or MRL, using hazard quotient (HQ) methodology as suggested by the USEPA.

A HQ, defined by the EPA, *is*

> *…the ratio of the estimated exposure dose of a contaminant (mg/kg/day) to the contaminant's RfD or MRL (mg/kg/day).*[45]

Note that, according to the USEPA, a linear increase in the HQ for a toxicant does not imply a linear increase in the likelihood or severity of systemic adverse effects. Thus, a HQ of 4.0 does not mean the concentration in the dose will be four times as toxic as that same substance would be if the HQ were equal to 1.0. An HQ of 4.0 also does not imply that adverse events will occur four times as often as if the HQ for the substance in question were 1.0. Rather, the USEPA suggests that an HQ or a hazard index (HI) that computes to less than 1.0 should be interpreted as "no cause for concern" whereas an HQ or HI greater than 1.0 "should indicate some cause for concern." Therefore, the SALG does not utilize HQ's to determine the likelihood of occurrence of adverse systemic health effects. Instead, in a manner similar to the USEPA's decision process, the SALG may utilize computed HQs as a point of departure for management decisions – assuming, for instance, that hazard quotients less than 1.0 are unlikely to be an issue while HQs greater than 1.0 might suggest that a regulatory action could be taken to ensure protection of public health. Similarly, risk assessors at the DSHS may utilize an HQ to determine the need for further study of a water body's fauna. Notwithstanding the above discussion, the oral RfD derived by the USEPA represents chronic consumption. Thus, regularly eating fish containing a toxic chemical, the HQ of which is less than 1 is unlikely to cause adverse systemic health effects, whereas routine consumption of fish or shellfish in which the HQ exceeds 1 represents a qualitatively unacceptable increase in the likelihood of systemic adverse health outcomes.

Although, as advised by the USEPA, the DSHS preferentially utilizes the RfD calculated by federal scientists for a specifically named contaminant, should no RfD be available for a contaminant, the USEPA advises risk assessors to consider using an RfD (or an MRL) for a contaminant of similar molecular structure, or one of similar mode or mechanism of action. For instance, no published RfD is available for Aroclor® 1260, so the DSHS uses the reference dose for Aroclor 1254 to assess the likelihood of systemic or noncarcinogenic effects of Aroclor 1260.[43]

In developing oral RfDs and MRLs, federal scientists review the extant literature to devise NOAELs, LOAELs, or BMDs from experimental studies. Uncertainty factors are then utilized to minimize potential systemic adverse health effects in people who are exposed through consumption of contaminated materials by accounting for certain conditions that may be undetermined by the experimental data: extrapolation from animals to humans (interspecies variability), intra-human variability, use of a subchronic study rather than a chronic study to determine the NOAEL, LOAEL, or BMD, and database insufficiencies.[42.,44] Vulnerable groups such as women who are pregnant or lactating, women who may become pregnant, infants, children, people with chronic illnesses, those with compromised immune systems, the elderly, or those who consume exceptionally large servings – all groups that risk assessors and the USEPA consider sensitive groups – also receive special consideration in calculation of an RfD. [44, 46]

The primary method for assessing the toxicity of component-based mixtures of chemicals in environmental media is the hazard index (HI). The USEPA recommends HI methodology for groups of toxicologically similar chemicals. Although knowing the mode or mechanism of action of chemicals of interest to risk assessors, the lack of this information however boils down to using the "similarity of target organs" as the definition of "toxicological similarity." The default procedure for calculating the HI for the exposure mixture chemicals is to add the hazard quotients (the ratio of the external exposure dose to the RfD) for all component chemicals affecting the same target organ or organ system.

Summing HQ's approximates the value the mixture's "hazard quotient" likely would have taken if all chemicals in the mixture could have been simultaneously tested (as a single chemical). For example, the HI for liver toxicity should approximate the degree of liver toxicity that would have been present if effects of the whole mixture were due to a single chemical. Target organs addressed by the HI's should be decided for each particular mixture assessment and a separate HI calculated for each toxic effect of concern. The mixture components to be included in the HI calculation are any chemical components showing the effect described by the HI, regardless of the critical effect upon which the RfD comes.

A note of caution: because the RfD is derived for the critical effect – the "toxic effect occurring at the lowest dose of a chemical" – an HI computed from HQs derived from RfDs may be overly conservative, thereby resulting in an exaggeration of health risk from consumption of the mixture of chemicals.

The USEPA states that

> *the HI is a quantitative decision aid that requires toxicity values as well as exposure estimates. When each organ-specific HI for a mixture is less than 1 and all relevant effects have been considered in the assessment, the exposure being assessed for potential systemic toxicity should be interpreted as* ***unlikely to result in significant toxicity****.*

And

When any effect-specific HI exceeds 1, concern exists over potential toxicity. As more HI's for different effects exceed 1, the potential for human toxicity also increases.

Thus,

Concern should increase as the number of effect-specific HI's exceeding 1 increases. As a larger number of effect-specific HI's exceed 1, concern over potential toxicity should also increase. As with HQs, this potential for risk is not the same as probabilistic risk; a doubling of the HI does not necessarily indicate a doubling of toxic risk.

Derivation and Application of Health-Based Assessment Comparison Values (HAC_{ca}) for Application to the Carcinogenic Effects of Consumed Chemical Contaminants

The DSHS calculates cancer-risk comparison values (HAC_{ca}) from the EPA's chemical-specific cancer potency factors (CPFs) – also known as slope factors (SFs) – derived through mathematical modeling from carcinogenicity studies. For carcinogenic outcomes, the DSHS calculates a theoretical lifetime excess risk of cancer for specific exposure scenarios for carcinogens, using a standard 70-kg body weight and assuming an adult consumes 30 grams of edible tissue per day. The SALG risk assessors incorporate two additional factors into determinations of theoretical lifetime excess cancer risk: (1) an acceptable lifetime risk level (ARL) [44] of one excess cancer case in 10,000 persons whose average daily exposure is equivalent and (2) daily exposure for 30 years. Comparison values used to assess the probability of cancer do not contain "uncertainty" factors as such. However, conclusions drawn from probability determinations infer substantial safety margins for all people by virtue of the models utilized to derive the slope factors (cancer potency factors) used in calculating the HAC_{ca}.

Because the calculated comparison values (HAC values) are conservative, exceeding a HAC value does not necessarily mean adverse health effects will occur. The perceived strict demarcation between acceptable and unacceptable exposures or risks is primarily a *tool* used by risk managers along with other information to make decisions about the degree of risk incurred by those who consume contaminated fish or shellfish. Moreover, comparison values for adverse health effects do not represent sharp dividing lines (bright-line divisions) between safe and unsafe exposures. For example, the DSHS considers it unacceptable when consumption of four or fewer meals per month of contaminated fish or shellfish would result in exposure to contaminant(s) in excess of a HAC value or other measure of risk. The DSHS also advises people who wish to minimize exposure to contaminants in fish or shellfish to eat a variety of fish and/or shellfish and to limit consumption of those species most likely to contain toxic contaminants. The DSHS aims to protect vulnerable subpopulations with its consumption advice, assuming that advice protective of vulnerable subgroups will also protect the general population from potential adverse health effects associated with consumption of contaminated fish or shellfish.

Children's Health Considerations

The DSHS recognizes that fetuses, infants, and children may be uniquely susceptible to adverse effects from exposure to toxic chemicals. As suggested by the USEPA and the ATSDR, the DSHS is aware that exceptional susceptibilities demand special attention. [47,48] Windows of vulnerability or "critical periods" exist during development. Critical periods occur particularly during early gestation (weeks 0 through 8), but can occur at any time during pregnancy, infancy, childhood, or adolescence – indeed, at any time during development – times when toxicants can impair or alter the structure or function of susceptible systems.[49] A growing body of evidence demonstrates that children may suffer disproportionately from environmental health risks. Children eat more food, drink more fluids, and breathe more air in proportion to their body weight than do adults. Children's small sizes and weights may diminish their protection from standard safety features; children may be more susceptible to exposures to toxicants because they put contaminated objects in their mouths or through hand-to-mouth activity, they transfer contaminated environmental media to their bodies. Unique early sensitivities may exist because organs and body systems continue to develop throughout infancy, childhood, and adolescence. Developmental stage may influence pharmacokinetic and/or pharmacodynamic mechanisms of toxicants, which could alter the biologically effective concentration of toxicant(s) at the target organ or could modulate target organ sensitivity to toxicants. Children's exposures to toxicants may be more extensive than adults' exposures because, children eat more food, drink more fluids, and breathe more air in proportion to their body weights than do adults. Children's small body sizes and weights might alter the concentration of toxicant at the target organ. Infants can ingest toxicants through breast milk – an exposure pathway that may go unrecognized (nonetheless, the advantages of breastfeeding outweigh the probability of significant exposure to infants through breast milk so women are encouraged to continue breastfeeding while limiting exposure of their infants through limitation of their intake of contaminated foodstuffs). Children may also experience toxicity at lower exposure doses than adults because children's organs may be more sensitive to the effects of toxicants and their systems could respond more extensively or with greater severity to a given dose than would an adult organ exposed to an equivalent toxicant dose.[50] In any case, if a chemical appears more toxic to fetuses, infants, or children than to adults, federal risk assessors would adjust RfDs, MRLs, or CPFs to assure protection of the immature system.[42] Additionally, in accordance with the ATSDR's *Child Health Initiative*[51] and the EPA's *National Agenda to Protect Children's Health from Environmental Threats*,[52] the DSHS further seeks to protect children from the possible negative effects of toxicants in fish by suggesting that this potentially sensitive subgroup consume smaller quantities of contaminated fish or shellfish than adults consume. Thus, the DSHS recommends that children weighing 35 kg or less and/or who are 11 years of age or younger limit exposure to contaminants in fish or shellfish by eating no more than four ounces per meal of the contaminated species. The DSHS also recommends that consumers spread these meals over time.

RESULTS

Laboratory Analytical Results

The GERG laboratory completed analyses and electronically transmitted the results to the SALG at the DSHS in January 2008. The laboratory reported the analytical results for pesticides and PCBs (122 samples), PCDFs/PCDDs, and metals (55 samples), and semivolatile organic compounds (SVOCs) and volatile organic compounds (VOCs; 14 samples).

Tables 2, 3, 4, and 5 contain summary results of metals, pesticides, PCBs, and PCDFs/PCDDs in fish and blue crab collected April through June 2006 from Trinity Bay and Upper Galveston Bay. Tables 2a through 2d present results of metals analyses. Tables 3a-3c contain pesticide data. Tables 4a-4c outline the results of PCB analyses and Tables 5a-5c the summary PCDF/PCDD data. The authors of this paper chose not to display the SVOC and VOC data because compounds occurred sporadically and at low concentrations. Unless otherwise stated, table summaries present the number of samples containing a toxicant/number tested, the mean concentration ± 1 standard deviation, and, in parentheses under the mean and standard deviation, the minimum and maximum detected concentrations.

Inorganic Contaminants

Cadmium, Arsenic, Lead, Mercury, Copper, Selenium, and Zinc

Fish and blue crab samples from Trinity Bay and Upper Galveston Bay contained no detectable cadmium (Table 2b). Inorganic constituents present at measurable levels in fish and blue crab samples from Trinity Bay and Upper Galveston Bay include total arsenic, mercury, lead, copper, selenium, and zinc. Fifty-one of 55 samples contained measurable arsenic (Table 2a). Black drum and gaftopsail catfish contained approximately six times more arsenic than other fish examined. Lead was present in 22 of 55 samples (Table 2c). The laboratory used the "J" designation to indicate concentrations estimated from points falling below the linear portion of the standard curve. All fish and blue crab assayed contained mercury (Table 2c). However, nine were estimated concentrations (J-values). The mean mercury concentration in all species examined was 0.136±0.137 mg/kg (Table 2c). A gaftopsail catfish contained the highest reported mercury concentration (0.566 mg/kg). All 55 samples contained copper (Table 2b); eleven copper concentrations were estimated (J-values). The mean copper concentration for all species was 1.416±2.518 mg/kg (Table 2b). Fifty-two of 55 samples contained selenium – two gaftopsail catfish and one blue crab contained no detectable selenium. The mean selenium concentration for all species was 0.573±0.314 mg/kg (Table 2c). All species also contained zinc (Table 2d), the average concentration of which was 13.014±15.000 mg/kg (Table 2d).

Organic Contaminants

Pesticides

The laboratory analyzed all fish and blue crab for thirty-four (34) pesticides (Tables 3a-3c). Trace[d] quantities of 1,2,4,5 tetrachlorobenzene, 1,2,3,4 tetrachlorobenzene, alpha HCH, pentachloroanisole, 2,4'-DDD, and dacthal were present in some fish and blue crab samples (data not presented). Six of 122 samples contained very low concentrations of dieldrin (data not presented). Seventy-two of 122 samples contained pentachlorobenzene (Table 3a). Sixty-seven of these samples contained pentachlorobenzene at levels below the laboratory's method detection limit and were reported as estimated or “J” concentrations. Five samples contained measurable quantities of pentachlorobenzene. Ninety-six of 122 samples contained hexachlorobenzene (Table 3a). Sixty-seven of these samples had estimated concentrations (J-values) below the laboratory’s method detection limit.

One-hundred and sixteen of 122 fish and blue crab samples contained low levels of compounds consistent with technical chlordane (mean concentration = 0.009±0.014 mg/kg; Table 3a). Some gaftopsail catfish, red drum, and spotted seatrout contained measurable, but minute, concentrations of chlordane (Table 3a). Chlordane in 60 samples was below the laboratory’s method detection limit. Black drum, southern flounder, and blue crab samples contained only estimable concentrations of total chlordane. A gaftopsail catfish contained the highest concentration of chlordane (0.092 mg/kg).

Very small quantities of 4,4'-DDT were reported in 20 fish from Trinity Bay and Upper Galveston Bay: black drum, blue crab, and southern flounder contained 4,4'-DDT at concentrations below the laboratory's detection limit, reported as estimated (J-values; data not shown). A gaftopsail catfish contained measurable 4, 4'-DDT (data on 4,4'-DDT not presented). Twenty-six of 122 samples contained 2,4'-DDE (Table 3b), 24 of which concentrations were below the detection limit (reported as J-values: estimated concentrations – see Table 3b). One-hundred and twenty of 122 samples contained 4,4'-DDE (mean concentration =0.010±0.020 mg/kg; Table 3b). Eighty-six of these, including some gaftopsail catfish and spotted seatrout, contained measurable concentrations of 4,4'-DDE (Table 3b). Thirty-one samples had only estimated concentrations. All fish samples contained detectable 4,4'-DDE as did 10 of 12 blue crab samples. Nineteen samples contained measurable but very low concentrations of 4,4'-DDD (mean concentration: 0.004±0.005 mg/kg; Table 3b). Eighty-three samples contained 4,4'-DDD at estimated concentrations.

Seventy-six of 122 fish and blue crab samples contained mirex. One sample contained measurable mirex; 75 contained estimated concentrations (J-values). Forty-six samples contained no identifiable mirex. Table 3c shows the overall mean concentration and the standard deviation of mirex as a very low 0.002±0.0003 mg/kg.

[d] *Trace: in analytical chemistry, a trace is an extremely small amount of a chemical compound, one present in a sample at a concentration below a standard limit. Trace quantities may be designated with the “less than” (<) sign or may also be represented by the alpha character “J” – called a “J-value” defining the concentration of a substance as near zero or one that is detected at a low level but that is not guaranteed quantitatively replicable.*

PCBs

For the Galveston Bay system, the present study marks the first instance of analysis of samples for PCB congeners instead of Aroclors®. Thus, the reader should not directly compare PCB concentrations in this report with Aroclors reported in previous studies of the Galveston Bay system.

Tables 4a and 4b contain summary statistics – by site and by species – for PCBs measured in fish and blue crab samples collected in 2006 from the Trinity Bay–Upper Galveston Bay complex. The laboratory analyzed each sample for all 209 PCB congeners. One or more of the 209 congeners was present in each fish and/or blue crab (Table 4c). No sample contained all 209 PCB congeners.

Table 4c shows summary statistics for PCBs in each species of fish and in blue crab samples without regard to collection site. Summary statistics for PCBs in each species revealed that gaftopsail catfish contained the highest mean concentration (0.099 ± 0.066 mg/kg; Table 4c) followed by spotted seatrout (0.051±0.032 mg/kg). The mean PCB concentration in blue crab samples – that species with the lowest average concentration of PCBs – was 0.010± 0.0004 mg/kg.

PCDFs/PCDDs

Tables 5a, 5b, and 5c contain summary statistics for PCDFs/PCDDs measured in fish and blue crab samples collected in 2006 from Trinity Bay and Upper Galveston Bay by species and sample site. The laboratory analyzed 55 fish and blue crab samples for 17 of the 210 possible PCDF/PCDD (135 PCDFs + 75 PCDDs) congeners. The congeners examined consist of 10 PCDFs and 7 PCDDs that contain chlorine substitutions in, at a minimum, the 2, 3, 7, and 8 positions on the dibenzofuran or dibenzo-*p*-dioxin nucleus and are the only congeners reported to pose dioxin-like adverse human health effects.[53] (Although 12 of the 209 PCB congeners – those often referred to as "coplanar PCBs," meaning the molecule can assume a flat configuration with both phenyl rings in the same plane – may also have dioxin-like toxicity, the SALG does not assess PCBs for dioxin-like qualities because the dioxin-like behavior has been less extensively evaluated). All 43 fish and 10 of 12 blue crab contained one or more of the 17 congeners (minimum-maximum TEQ PCDF/PCDD concentration; ND-15.4675 pg/g – or ng/kg). No samples contained all 17 congeners. Gaftopsail catfish contained the highest mean TEQ concentration (2.5124 ± 3.8544 pg/g; Table 5c), followed by spotted seatrout, which contained a mean concentration of 1.0555±0.9698 pg/g (ng/kg). The mean PCDF/PCDD TEQ in southern flounder – the species containing the lowest levels of PCDFs/PCDDs – was 0.0322± 0.0413 pg/g (ng/kg).

SVOCs

The SALG submitted 14 samples for analysis of SVOCs. The GERG laboratory reported only sporadic SVOCs in fish and blue crab samples from Trinity Bay and Upper Galveston Bay (data not presented). Bis (2-ethylhexylphthalate) (di-(2-ethylhexyl) phthalate; DEHP), an ubiquitous plasticizer, was present in 10 of 14 samples, four of which contained only trace quantities (BDL); six samples contained low but measurable concentrations of DEHP. One sample, a gaftopsail catfish, contained a trace of di-n-butyl phthalate (DBP) while another sample contained a trace of phenol. No other SVOCs were reported present in fish or blue crab collected in 2006 from Upper Galveston Bay or Trinity Bay.

VOCs

The laboratory analyzed the same 14 samples for VOCs as were analyzed for SVOCs (data not shown). All 14 samples contained acetone (5.4 mcg/kg – 609 mcg/kg), along with methylene chloride (20 mcg/kg – 282 mcg/kg). Three samples contained traces of 1,2- dichloroethane. Five contained low concentrations of benzene. Toluene occurred at low levels in eight samples. Nine samples contained low levels of naphthalene (highest concentration: 213 mcg/kg). As seen from quoted concentrations, VOCs in these samples generally occurred at only very low levels, with many estimated concentrations (J-values) and, as is often the case, most VOCs detected in the samples were also detected in one or more procedural blanks, suggesting the possibility of post-collection contamination or, perhaps, tissue necrosis.

DISCUSSION

Risk Characterization

Because variability and uncertainty are inherent to quantitative assessment of risk, the calculated risks of adverse health outcomes from exposure to toxicants can be orders of magnitude above or below actual risks. Variability in calculated and actual risk depends upon factors such as the use of animal studies instead of human studies, use of subchronic studies rather than chronic studies, interspecies variability, intra-species variability, and database inadequacy. Since most factors used to calculate comparison values result from experimental studies conducted in the laboratory on nonhuman subjects, variability and uncertainty might arise from study chosen as the "critical" one, the species/strain of animal used in the critical study, the target organ selected as critical, the exposure periods, exposure route, doses, or variations in other conditions.[42] Despite these limitations, risk assessors must calculate parameters to represent potential toxicity to humans who consume contaminants in fish and other environmental media. The DSHS calculated risk parameters for systemic and cancerous endpoints in those who would consume fish and crab from the Trinity Bay and Upper Galveston Bay. Conclusions and recommendations predicated upon the stated goal of the DSHS to protect human health follow the present discussion of findings.

Characterization of Systemic (Noncancerous) Health Effects from Consumption of Fish and Blue Crab from Trinity Bay and Upper Galveston Bay

Inorganic Contaminants

Arsenic, Cadmium, Lead, Copper, Mercury, Zinc, and Selenium

Almost all arsenic in finfish appears as organic arsenic, with an estimated maximum of 10% inorganic arsenic.[25] Table 2a gives both total arsenic as measured and the inorganic arsenic calculated from total arsenic. Gaftopsail catfish contained the highest average calculated concentration of inorganic arsenic (0.112 mg/kg), a concentration that did not exceed HAC values for inorganic arsenic. The overall average inorganic arsenic in all species was 0.057 mg/kg, a concentration less than one-tenth the HAC_{nonca} for inorganic arsenic in seafood and approximately 1/6 that of the HAC_{ca}. These data suggest that consumption of fish and blue crab from Trinity Bay and Upper Galveston Bay that presumably contain inorganic arsenic will not adversely affect human health.

No fish or blue crab sample from Trinity Bay and Upper Galveston Bay (Table 2b) contained detectable cadmium. Therefore, at levels below the MDL, cadmium is not expected to affect human health negatively.

Twenty-two of 55 samples, including six composite blue crab samples, contained low levels of inorganic lead. Inorganic lead is a neurotoxicant in the fetus, children, and – at high levels – in adults.[40] In children, inorganic lead in blood at levels much lower than the Centers of Disease Control and Prevention's (CDC) published blood lead level (BLL) of concern (=10 mcg/dL blood) have reportedly been associated with subtle neurotoxicity.[35, 36] No threshold for neurotoxic effects of lead on children's central nervous system (CNS) development and function so far exists. Both remote and more recent reports suggest that no such threshold exists. Although the CDC agrees with this assessment, the agency recently elected to retain its previously determined level of concern for children's blood lead levels (PbB) because it believes arbitrary reduction of the level of concern for a contaminant with no established toxicity threshold could be a capricious decision.[35,36] The HAC_{nonca} for lead in fish (0.6 mg/kg), developed from the USEPA's IEUBK model, is fundamentally different from other HAC values used to assess contaminants in fish or shellfish. Rather than a concentration in fish that, if consumed, is unlikely result in adverse health effects, the HAC_{nonca} for lead HAC_{nonca} for inorganic lead is a concentration in fish or shellfish that – if consumed by a child under the conditions and assumptions of this report – could raise that child's PbB to a concentration greater than 10 mcg/dL. Inorganic lead in fish and blue crab samples from Trinity Bay and Upper Galveston Bay did not reach concentrations likely to increase a child's blood lead level to the CDC's level of concern for lead in children's blood. The DSHS therefore concludes that consumption of lead-containing fish or blue crab from Trinity Bay and Upper Galveston Bay will not likely negatively affect children's health nor will the health of adults be negatively affected by the presence of small quantities of lead in these fish and blue crabs.

Mercury in fish (methylmercury) is a known fetal neurotoxicant that readily reaches the fetal brain through the maternal-fetal circulation. In this context, it is important to know that most – if not all – human exposures to methylmercury derive from consumption of mercury-contaminated fish. Dietary methylmercury is almost completely absorbed into the blood and is distributed to all tissues, including the brain.[54] The HAC_{nonca} value for methylmercury in fish or shellfish – based on the neurodevelopmental effects of methylmercury –has been set by the DSHS at 0.7 mg/kg, derived from the ATSDR's methylmercury-based MRL of 0.0003 mg/kg –day.[55] All 55 samples contained mercury (as total mercury). The highest mercury concentration in this data set occurred in a gaftopsail catfish containing 0.566 mg/kg. The average concentration of mercury in all samples (Table 2c) was approximately 1/5 the HAC_{nonca} value for methylmercury. No sample contained mercury in excess of the HAC_{nonca} value, suggesting that consumption of fish and blue crab from Trinity Bay and Upper Galveston Bay containing mercury will not likely adversely affect human neurocognitive health

Copper (Table 2b) and zinc (Table 2d) were present in all 55 samples, reported at levels far below the HAC_{nonca} values for these metals. Fifty-two of 55 samples contained selenium (Table 2c) at levels well below concentrations likely to affect human health adversely. The DSHS concludes from these data that consumption of fish or shellfish from Trinity Bay and Upper Galveston Bay containing zinc, copper and/or selenium is unlikely to result in adverse systemic effects. In fact, copper, zinc, and selenium are trace elements essential for normal bodily functions in humans and in many other species.[56]

Organic Contaminants

<u>Pesticides</u>

The laboratory reported very low levels of several pesticides (mostly chlorinated compounds) in fish and blue crab samples from Trinity Bay and Upper Galveston Bay. Among the pesticides in these samples were pentachlorobenzene, hexachlorobenzene, technical chlordane, various DDT derivatives, and mirex. No pesticide in fish or blue crab samples occurred at a concentration approaching or exceeding the respective HAC_{nonca} value for the pesticide under examination.

<u>SVOCs</u>

SVOCs were of no particular significance in samples collected in 2006 from Upper Galveston Bay or Trinity Bay. One sample contained a small quantity of phenol. The laboratory reported low concentrations of two other SVOCs – the plasticizers bis (2-ethylhexyl) phthalate and di-n-butyl phthalate – in some fish. No SVOCs in the present samples exceeded the HAC_{nonca} for those compounds (data not presented). At the very low levels observed in fish or blue crab samples in the present study, consumption of fish or blue crab from Trinity Bay and Upper Galveston Bay is not likely to result in adverse human health outcomes.

<u>VOCs</u>

Some samples from Trinity Bay and Upper Galveston Bay contained traces of one or more VOCs (data not shown), including acetone, methylene chloride, 1,2–dichloroethane acrolein, benzene, toluene, and naphthalene. No VOCs exceeded a HAC value, so none should cause adverse systemic health effects in humans if consumed in fish or blue crab from Trinity Bay and Upper Galveston Bay.

<u>PCBs</u>

The GERG laboratory analyzed PCBs in all 122 fish and blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay. All samples contained one or more of the possible 209 PCB congeners (Tables 4a and 4b). No single sample contained all 209 PCBs nor did all reported PCBs exceed the HAC_{nonca} for these contaminants. Tagging data indicate that fish move throughout the estuarine system. Therefore, the present study does not attempt to evaluate consumption of fish or crab samples from individual collection sites for risk of site-specific adverse health effects. Rather, the study represents a "snapshot" of risk throughout the bays on the day of sampling. Table 4c contains the mean concentration, standard deviation, with minimum and maximum concentrations of PCBs in each species collected in 2006 from these bays listed beneath the mean and standard deviation. Although all fish and blue crab samples contained PCBs (Tables 4a, 4b, and 4c), only PCBs in gaftopsail catfish and spotted seatrout exceeded the HAC_{nonca} value for PCBs (0.047 mg/kg). PCB concentrations in species other than gaftopsail catfish and spotted seatrout averaged only 25% to 34% of the HAC_{nonca}.

Using only the 43 congeners of PCBs utilized by other investigators,[28 29] the SALG risk assessors calculated HQs for each fish species and for blue crab (Tables 6a, 6b, and 6c). The HQ for PCBs in gaftopsail catfish was 2.12 (Table 6a). In spotted seatrout, the HQ was 1.09 (Table 6a). The HQs for species other than gaftopsail catfish and spotted seatrout were less than 1.0. The HQ for PCBs in fish species combined was, coincidentally, 1.09. Adding blue crab to fish reduced the overall HQ to 1.01. These data clearly attribute the major portion of the risk for noncancerous adverse health effects from consumption of PCBs in fish from Trinity Bay and Upper Galveston Bay to consumption of gaftopsail catfish and/or spotted seatrout.

Meal consumption calculations may be useful for decisions about consumption advice or regulatory actions. The SALG risk assessors used the HQs for PCBs in blue crab and fish to calculate the number of 8-ounce meals of fish species or blue crab from Trinity Bay and Upper Galveston Bay that adults in general could consume without significant risk adverse systemic effects (Table 6a). The SALG estimated these groups could consume 0.4 (8-ounce) meals per week of gaftopsail catfish or 0.8 (8-ounce) meals per week of spotted seatrout. PCB concentrations in other fish species and in blue crab species were well below the HAC_{nonca} for PCBs, as reflected in the HQs and numbers of meals calculated for those species (Table 6a). Therefore, the DSHS suggests only that people limit their consumption of catfish and spotted seatrout from Trinity Bay and Upper Galveston Bay (Table 6a).

PCDDs/PCDFs

The laboratory analyzed 55 fish and blue crab for PCDFs and PCDDs. Tables 5a and 5b list the species tested at each collection site, the number of each species analyzed, the number of samples of each species that contained PCDFs/PCDDs and the TEQ of combined PCDFs/PCDDs in each species at each site. All 43 fish and 10 of 12 blue crab samples contained one or more PCDFs/PCDDs. No fish or blue crab sample contained all possible PCDF/PCDD congeners. Again, the mobility of fish limits the use of "collection site" as a variable in this assessment. Table 5c shows the mean TEQ of PCDFs/PCDDs for each species independent of collection site, for all fish species combined, for blue crab, and for all fish species combined with blue crab. Gaftopsail catfish contained the highest mean concentrations (in TEQs) of PCDFs/PCDDs. The mean concentration of PCDFs/PCDDs in gaftopsail catfish exceeded the HAC_{nonca} for 2,3,7,8-TCDD (2.33 pg/g). PCDFs/PCDDs in other species did not exceed the HAC_{nonca}. HQ's were generated for each species, for combined fish species, and for fish and blue crab species. The HQ for gaftopsail catfish was 1.08 (Table 6a).

These data suggest that, in this instance, PCDFs/PCDDs contribute a relatively lower portion to the predicted toxicity from consumption of fish or blue crab from these bays than do PCBs (Tables 6a, 6b, and 6c). It is probable that consumption of fish from Trinity Bay and Upper

Galveston Bay that contain PCDFs/PCDDs will be limited by PCBs rather than by the PCDFs and PCDDs in Galveston Bay.

Characterization of Lifetime Excess Cancer Risk from Consumption of Fish and Blue Crab from Trinity Bay and Upper Galveston Bay

Calculated lifetime excess cancer risk from consumption of fish and/or blue crab from Trinity Bay and Upper Galveston Bay showed that PCBs alone did not increase the risk of cancer in those consuming any fish species represented in the sample. Nor did blue crab contain PCBs in excess of the HAC_{ca} (2.33 pg/g; Tables 4a-4c; 7a-7c).

The SALG ultimately combined collection sites for each species to determine systemic and/or lifetime excess cancer risk because tagging data from the TPWD indicate that spotted seatrout move throughout the estuarine system, Nonetheless, risk assessors found it useful to examine site-specific data to see if differences in toxicant concentrations within species occurred among sites. Assessors observed that gaftopsail catfish caught near the HL&P outfall contained PCDFs/PCDDs at levels that approximately doubled the lifetime excess risk of cancer from 1 in 10,000 equivalently exposed persons to about 1 in 5,600 people with equivalent exposures (Table 7b). With collection sites collapsed, lifetime excess cancer risk was 1 in 9,259 people equivalently exposed (Table 7b). The SALG risk assessors therefore concluded that those recreational fishers who – rather than concentrating fishing activities on areas near the HL&P plant – would catch gaftopsail catfish throughout Trinity Bay and Upper Galveston Bay would likely have a low increase in their lifetime excess cancer risk.

Characterization of Cumulative Systemic Health Effects and Cumulative Excess Lifetime Cancer Risk from Consumption of Fish or Blue Crab from Trinity Bay and Upper Galveston Bay

Cumulative Systemic Effects

Cumulative adverse health effects may be of concern if exposure media contain more than one contaminant (mixtures of contaminants).

In the present risk characterization, risk assessors observed various combinations of metals, pesticides, VOCs, SVOCs, PCBs, and PCDFs/PCDDs in samples collected from Trinity Bay and Upper Galveston Bay. Combinations of some of the observed contaminants could potentially increase damage to the human liver.[57]

Risk assessors at SALG did not calculate cumulative effects for metals because HQs for individual metals did not meet criteria for calculating additive effects or because the constants needed to determine such effects (RfDs, MRLs, or CPFs) were not available.[57]

The HQs for pesticides, VOCs, and SVOCs (not shown), many of which may affect the same target organ (for instance, the liver) or have the same mode or mechanism of action did not exceed 1.0 making it unlikely that combinations of these chemicals in fish or blue crab from Trinity Bay and Upper Galveston Bay would result in cumulative toxicity.[58]

While the greater portion of potential systemic toxicity from consuming fish or blue crab from Trinity Bay and Upper Galveston Bay is clearly due to PCBs in gaftopsail catfish and/or spotted seatrout (Table 6a), risk assessors identified some cumulative effects. For instance, while the HQ for PCBs in gaftopsail catfish is 2.12 (Table 6a) with a suggested consumption limit of 0.4 meals per week (less than two meals per month). The cumulative effect of PCBs and PCDFs/PCDDs in gaftopsail catfish (1.08; HI = 3.2) is a further reduction in calculated allowable consumption of gaftopsail catfish from Trinity Bay and Upper Galveston Bay (from 0.4 to 0.3 meals per week; Table 6a). Although average PCDF/PCDD concentration in spotted seatrout did not exceed the HAC_{nonca} and the HQ was less than 1.0, dose addition yielded HI of 1.55, decreasing suggested consumption of spotted seatrout from 0.8 meals/week (PCBs) to 0.6 meals/week (combined PCBs and PCDFs/PCDDs; Table 6a). Hazard indices for PCBs and PCDFs/PCDDs in blue crab, black drum, red drum, and southern flounder from Trinity Bay and Upper Galveston Bay did not exceed 1.0, confirming the insignificance of additive effects of PCBs and PCDFs/PCDDs in those species (Table 6a).

Cumulative Carcinogenicity

In most assessments of cancer risk from environmental exposures to chemical mixtures, researchers have considered any increase in cancerous or benign growths in one or more organs as cumulative, no matter the mode or mechanism of action of the contaminant. In this assessment, risk assessors added the calculated carcinogenic effect of PCDFs/PCDDs to that of PCBs (Table 7a). In each instance, addition of the cancer risk numbers for these chemicals increased the theoretical lifetime excess cancer risk, albeit the increase in most did not elevate lifetime excess cancer risk to a level greater than the acceptable risk level (ARL) of 1 excess cancer in 10,000 persons equivalently exposed. However, adding the carcinogenic risk of PCDFs/PCDDs to PCBs in gaftopsail catfish, did increase the calculated cumulative theoretical lifetime excess cancer risk, thereby decreasing the number of meals an adult could eat to slightly less than one meal per week (0.9 meals/week) (Table 7a).

CONCLUSIONS

SALG risk assessors prepare risk characterizations to assess public health hazards from consumption of fish and shellfish harvested from Texas water bodies by recreational or subsistence fishers and their families. If indicated, SALG risk assessors may suggest strategies for reducing risks to the health of those who would eat contaminated fish or shellfish from Texas waters to risk managers at the DSHS – including the Texas Commissioner of Health.

This study addressed the public health implications of consuming targeted species of fish from Trinity Bay and Upper Galveston Bay. Risk assessors from the SALG conclude from the present characterization of potential adverse health effects from consuming contaminated fish from Trinity Bay and Upper Galveston Bay

1. That gaftopsail catfish collected from Trinity Bay and Upper Galveston Bay in 2006 contained PCBs at an average concentration that exceeded – by a factor of 2 – the DSHS HAC_{nonca} for PCBs (Table 4c). Based upon the consequent increase in the HQ for PCBs (Table 6a) consumption of gaftopsail catfish containing PCBs could increase the

likelihood of systemic adverse health effects. Gaftopsail catfish also contained PCDFs/PCDDs that slightly exceeded the DSHS HAC_{nonca} value for PCDFs/PCDDs (Table 5c). While the risk of systemic adverse health effects from consuming PCDFs/PCDDs in gaftopsail catfish is small (Table 6a), these fish are likely contaminated with both PCBs and PCDFs/PCDDs (Tables 4c and 5c). The combined effects of PCBs and PCDFs/PCDDs on organs other than the critical ones may be more likely (Table 6a). Therefore, unlimited consumption of gaftopsail catfish from Trinity Bay and Upper Galveston Bay **poses an apparent hazard to human health.**

2. That the calculated lifetime excess cancer risk from consumption of gaftopsail catfish containing either PCBs or PCDFs/PCDDs was not elevated (Table 7c). Calculated lifetime excess cancer risk from consuming gaftopsail catfish containing both PCBs and PCDFs/PCDDs was, on the other hand, slightly increased, rising from fewer than 1 excess cancer in 10,000 equivalently exposed persons to approximately 1 excess cancer in 9259 (1.08 in 10,000) equally-exposed persons (Table 7a). The small increase in calculated risk of cancer means that unlimited consumption (more than 1 meal per week) of gaftopsail catfish from Trinity Bay and Upper Galveston Bay containing both PCBs and PCDFs/PCDDs **poses an apparent hazard to health.**

3. That the average concentration of PCBs in spotted seatrout from Trinity Bay and Upper Galveston Bay slightly exceeded the HAC_{nonca} for PCBs (Table 4c). Based on the consequent increase in the HQ for PCBs (Table 6a) consumption of spotted seatrout containing PCBs could increase the likelihood of systemic adverse health effects. Spotted seatrout also contained PCDFs/PCDDs at concentrations that did not exceed the DSHS HAC_{nonca} value for PCDFs/PCDDs (Table 5c). While there is no apparent risk of systemic adverse health effects from consuming PCDFs/PCDDs in spotted seatrout (Table 6a), the combined effects of PCBs and PCDFs/PCDDs increase the likelihood of systemic adverse health effects. Therefore, unlimited consumption of spotted seatrout from Trinity Bay and Upper Galveston Bay **poses an apparent hazard to human health.**

4. That the calculated cumulative excess lifetime cancer risk from consumption of spotted seatrout containing either PCBs or PCDFs/PCDDs or combined PCBs and PCDFs/PCDDs at concentrations similar to those observed in the 2006 samples **poses no apparent hazard to human health from cancer.**

5. That black drum, red drum, southern flounder, and blue crab collected from Trinity Bay and Upper Galveston Bay during 2006 did not contain contaminants at concentrations that would increase the calculated chances of adverse systemic or cancerous effects – either in isolation or in combination – in those who consume these fish species. Neither would consumption of blue crab from Trinity Bay or Upper Galveston Bay increase the likelihood of systemic or cancerous outcomes from consumption. Therefore, consumption of black drum, red drum, southern flounder, and/or blue crab species **poses no apparent hazard to human health.**

RECOMMENDATIONS

Risk managers at the DSHS have established criteria for issuing fish consumption advisories based on approaches suggested by the USEPA.[22, 24, 59] If a risk characterization confirms that eating four or fewer meals per month (adults: eight ounces per meal; children: four ounces per meal) of fish or shellfish from the water body under investigation could pose a hazard to human health, risk managers at the DSHS may recommend limited consumption of fish or shellfish from that water body. Alternatively, the DSHS may ban possession of fish from the affected water body. Fish or shellfish possession bans are enforceable under subchapter D of the Texas Health and Safety Code, part 436.061(a).[60] Declarations of prohibited harvesting areas are enforceable under the Texas Health and Safety Code, Subchapter D, parts 436.091 and 436.101[60] Advice on consumption of contaminated fish or shellfish from the DSHS carries no penalty for noncompliance. Consumption advisories, instead, inform the public of potential health hazards from consuming contaminated fish or shellfish from Texas waters. With this information, members of the public can make informed decisions about whether – and how much – contaminated fish or shellfish they wish to consume.

The SALG of the DSHS concludes from this risk characterization that consuming gaftopsail catfish and/or spotted seatrout from Trinity Bay and Upper Galveston Bay **poses an apparent hazard to public health**. Therefore, the SALG recommends

1. That the DSHS extends the extant advisory (ADV-28) that presently covers the Houston Ship Channel and the San Jacinto River to include all catfish and spotted seatrout from Trinity Bay and Upper Galveston Bay because these species contain PCBs and/or PCDFs/PCDDs at levels that could increase the risk of adverse systemic health effects or, in some instances, cancer, in those who regularly consume these species.

2. That the DSHS advises people that it is not necessary to limit consumption of black drum, red drum, southern flounder, or blue crab from Upper Galveston Bay and/or Trinity Bay.

3. That the DSHS continues to monitor fish and shellfish from Trinity Bay and Upper Galveston Bay for changes in contaminants or in contaminant concentrations that would necessitate a change in consumption advice for fish or shellfish from these water bodies.

PUBLIC HEALTH ACTION PLAN

Communication to the public of new and continuing possession bans or consumption advice – or the removal of either advisories or bans – is essential to effective management of risk from consuming contaminated fish. In fulfillment of the responsibility for communication, the DSHS takes several steps. The agency publishes fish consumption advisories and bans in a booklet available to the public through the SALG. To receive the booklet and/or the data, please contact the SALG at 1-512-834-6757.[61] The SALG also posts the most current information about advisories, bans, and the removal of either on the internet at http://www.dshs.state.tx.us/seafood. The SALG regularly updates this Web site. The DSHS also provides the USEPA(http://epa.gov/waterscience/fish/advisories/), the Texas Commission on Environmental

Quality (TCEQ; http://www.tceq.state.tx.us), and the Texas Parks and Wildlife Department (TPWD; http://www.tpwd.state.tx.us) with information on all consumption advisories and possession bans. Each year, the TPWD informs the fishing and hunting public of consumption advisories and fishing bans on its Web site and in an official hunting and fishing regulations booklet available at many state parks and at all establishments selling Texas fishing licenses.[62]

Readers may direct questions about the scientific information or recommendations in this risk characterization to risk managers at the Seafood and Aquatic Life Group (SALG) at 512-834-6757 or may find the information at the SALG's Web site (http://www.dshs.state.tx.us/seafood). The EPA's IRIS Web site (http://www.epa.gov/iris/) contains information on environmental contaminants found in food and environmental media. The ATSDR, Division of Toxicology (888-42-ATSDR or 888-422-8737 or the ATSDR's Web site (http://www.atsdr.cdc.gov) supplies brief information via ToxFAQs.® ToxFAQs are available on the ATSDR website in either English http://www.atsdr.cdc.gov/toxfaq.html) or Spanish (http://www.atsdr.cdc.gov/es/toxfaqs/es _toxfaqs.html). The ATSDR also publishes more in-depth reviews of many toxic substances in its *Toxicological Profiles.* To request a copy of the ToxProfiles™ CD-ROM or ToxFaqs™ readers may call 1-800-CDC-INFO (1-800-232-4636) or email requests to cdcinfo@cdc.gov. Many Toxicological Profiles are also available for downloading from the ATSDR's Web site (http://www.ATSDR.cdc.gov).

Figure 1. Trinity Bay and Upper Galveston Bay Sample Site Map

TABLES

Table 1. Sample number, species, length, and weight of fish and blue crab collected from Trinity Bay and Upper Galveston Bay, April through June 2006.

Sample Number	Species	Length (mm)	Weight (g)
Site 1 Pine Gully			
GAL21	Spotted seatrout	542	1893
GAL22	Spotted seatrout	577	1871
GAL23	Spotted seatrout	434	858
GAL24	Gaftopsail Catfish	592	2257
GAL25	Gaftopsail Catfish	580	1833
GAL26	Gaftopsail Catfish	628	2211
GAL27	Black Drum	600	3651
GAL28	Black Drum	705	4447
GAL31	Spotted seatrout	416	753
GAL32	Spotted seatrout	482	1413
GAL33	Spotted seatrout	440	926
GAL34	Blue crab	156[e]	
GAL35	Spotted seatrout	583	2121
GAL36	Red Drum	500	1395
GAL37	Southern Flounder	415	831
GAL38	Blue crab	143[e]	
GAL103	Spotted seatrout	434	817
GAL104	Spotted seatrout	337	344
Site 2 Clifton Beach			
GAL1	Spotted seatrout	539	1858
GAL2	Spotted seatrout	461	982
GAL3	Spotted seatrout	400	730
GAL4	Spotted seatrout	440	921
GAL5	Spotted seatrout	445	1079
GAL6	Spotted seatrout	397	711
GAL7	Spotted seatrout	434	950
GAL8	Spotted seatrout	480	1301
GAL9	Spotted seatrout	421	905
GAL10	Spotted seatrout	445	998
GAL11	Spotted seatrout	520	1616
GAL12	Spotted seatrout	480	1316
GAL13	Spotted seatrout	440	994
GAL14	Spotted seatrout	425	858
GAL15	Southern Flounder	360	585
GAL16	Southern Flounder	367	665
GAL17	Black Drum	917	11759

[e] *Length recorded is the average of the carapace width of the four+ blue crab samples composited to form each composite blue crab sample*

Table 1. Sample number, species, length, and weight of fish and blue crab collected from Trinity Bay and Upper Galveston Bay, April through June 2006.

Sample Number	Species	Length (mm)	Weight (g)
Site 2 Clifton Beach Continued			
GAL18	Gaftopsail Catfish	612	2187
GAL19	Gaftopsail Catfish	587	2025
GAL20	Gaftopsail Catfish	570	1893
GAL29	Blue crab	168[e]	
GAL30	Blue crab	153[e]	
Site 3 Lone Oak Bayou			
GAL39	Spotted seatrout	547	1964
GAL40	Red drum	550	2191
GAL41	Red drum	543	1830
GAL42	Red drum	532	1621
GAL44	Black drum	764	6100
GAL45	Southern flounder	433	1345
GAL46	Gaftopsail catfish	540	1448
GAL47	Gaftopsail catfish	511	1064
GAL48	Blue crab	151[e]	
GAL49	Blue crab	146[e]	
Site 4 Trinity River			
GAL60	Red drum	518	1630
GAL61	Spotted seatrout	499	1527
GAL62	Spotted seatrout	450	849
GAL63	Spotted seatrout	507	1311
GAL64	Black drum	910	11895
GAL66	Gaftopsail catfish	662	2551
GAL68	Gaftopsail catfish	552	1612
GAL69	Southern flounder	432	976
Site 5 HL&P Outfall			
GAL71	Spotted seatrout	455	1105
GAL72	Spotted seatrout	392	684
GAL73	Spotted seatrout	370	560
GAL74	Spotted seatrout	397	659
GAL75	Spotted seatrout	380	579
GAL76	Spotted seatrout	359	440
GAL77	Southern flounder	362	593
GAL78	Gaftopsail catfish	562	1614
GAL79	Spotted seatrout	530	1834
GAL80	Spotted seatrout	462	1043
Site 5 HL&P Outfall Continued			
GAL81	Spotted seatrout	431	902
GAL82	Spotted seatrout	368	518
GAL83	Spotted seatrout	340	427

Table 1. Sample number, species, length, and weight of fish and blue crab collected from Trinity Bay and Upper Galveston Bay, April through June 2006.

Sample Number	Species	Length (mm)	Weight (g)
GAL84	Gaftopsail catfish	604	1838
GAL85	Gaftopsail catfish	643	2255
GAL86	Gaftopsail catfish	532	1327
GAL87	Black Drum	494	1872
GAL88	Spotted seatrout	425	789
GAL89	Spotted seatrout	430	820
GAL90	Spotted seatrout	431	905
GAL91	Spotted seatrout	350	416
GAL92	Blue crab	173[e]	
GAL93	Blue crab	184[e]	
GAL94	Blue crab	164[e]	
GAL95	Blue crab	178[e]	
GAL96	Spotted seatrout	390	621
GAL97	Spotted seatrout	399	647
GAL98	Spotted seatrout	347	460
GAL99	Spotted seatrout	362	519
GAL100	Spotted seatrout	385	624
GAL101	Spotted seatrout	351	426
GAL102	Spotted seatrout	305	272
GAL107	Spotted seatrout	375	533
GAL108	Spotted seatrout	375	506
GAL109	Spotted seatrout	385	564
GAL110	Spotted seatrout	487	1086
GAL111	Spotted seatrout	394	584
GAL112	Spotted seatrout	442	861
GAL113	Spotted seatrout	426	738
GAL114	Spotted seatrout	434	789
GAL115	Spotted seatrout	466	1029
GAL116	Spotted seatrout	418	754
GAL117	Spotted seatrout	454	929
GAL118	Spotted seatrout	450	891
GAL119	Spotted seatrout	438	864
GAL120	Spotted seatrout	448	971
GAL121	Spotted seatrout	385	595
GAL122	Spotted seatrout	447	839
Site 5 HL&P Outfall Continued			
GAL123	Spotted seatrout	395	672
GAL124	Spotted seatrout	420	740
GAL128	Red drum	585	2206
GAL129	Spotted seatrout	452	918
Site 6 Umbrella Point			

Table 1. Sample number, species, length, and weight of fish and blue crab collected from Trinity Bay and Upper Galveston Bay, April through June 2006.

Sample Number	Species	Length (mm)	Weight (g)
GAL50	Black drum	510	1943
GAL51	Black drum	597	3390
GAL52	Red drum	538	1756
GAL53	Spotted seatrout	450	940
GAL54	Spotted seatrout	402	637
GAL55	Spotted seatrout	523	1483
GAL56	Southern Flounder	443	1052
GAL57	Gaftopsail catfish	605	2452
GAL58	Gaftopsail catfish	630	2410
GAL59	Gaftopsail catfish	585	1994
GAL105	Blue crab	165[e]	
GAL106	Blue crab	144[e]	

Table 2a. Arsenic (mg/kg) in fish and/or blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay.

Species	# Detected/ # Sampled	Total Arsenic Mean Concentration ± S.D. (Min-Max)	Inorganic Arsenic Mean Concentration[f]	Health Assessment Comparison Value (mg/kg) [g]	Basis for Comparison Value
Black drum	6/6	1.043 ±0.722 (0.298-2.324)	**0.104**	0.7 0.362	EPA chronic oral RfD for Inorganic arsenic: 0.0003 mg/kg–day EPA oral slope factor for inorganic arsenic: 1.5 per mg/kg–day
Gaftopsail catfish	14/14	1.121 ±0.662 (0.368-2.762)	**0.112**		
Red drum	6/6	0.151 ±0.067 (0.032-0.208)	**0.015**		
Southern flounder	4/5	0.165 ±0.099 (0.012-0.264)	**0.017**		
Spotted seatrout	10/12	0.120 ±0.079 (0.012-0.238)	**0.012**		
Blue crab	11/12	0.499 ±0.240 (0.013-0.268)	**0.050**		
All species	51/55	0.566 ±0.594 (0.012-2.762)	**0.057**		

[f] *Most arsenic in fish and shellfish occurs as organic arsenic, considered virtually nontoxic. For risk assessment calculations, the SALG assumes that total arsenic is composed of 10% inorganic arsenic in fish and shellfish tissues.*

[g] *Derived from the MRL or RfD for noncarcinogens or the USEPA slope factor for carcinogens; assumes a body weight of 70 kg, and a consumption rate of 30 grams per day, and assumes a 30-year exposure period for carcinogens and an excess lifetime cancer risk of $1x10^{-4}$.*

Table 2b. Inorganic contaminants (mg/kg) in fish and/or blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay.

Species	# Detected/ # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (mg/kg)	Basis for Comparison Value
Cadmium				
Black drum	0/6	ND[h]	0.47	ATSDR chronic oral MRL: 0.0002 mg/kg–day
Gaftopsail catfish	0/14	ND		
Red drum	0/6	ND		
Southern flounder	0/5	ND		
Spotted seatrout	0/12	ND		
Blue crab	0/12	ND		
All species	0/55	ND		
Copper				
Black drum	6/6	0.187 ±0.106 (BDL[i]-0.310)	333	National Academy of Science Upper Limit: 0.143 mg/kg–day
Gaftopsail catfish	14/14	0.410 ±0.171 (0.240-0.850)		
Red drum	6/6	0.229 ±0.093 (0.136-0.358)		
Southern flounder	5/5	0.071 ±0.039 (BDL-0.119)		
Spotted seatrout	12/12	0.097 ±0.046 (BDL-0.179)		
Blue crab	12/12	5.676 ±2.382 (BDL-10.343)		
All species	55/55	1.416 ±2.518 (BDL-10.343)		

[h] *ND: "Not Detected:" – Concentrations were not reported because the contaminant was not present in a sample at a concentration greater than the laboratory's Method Detection Limit (MDL).*

[i] *BDL: "Below Detection Limit" – Contaminant concentration was lower than the laboratory's method detection limit but was estimated from the standard curve ("J" value). A "J" qualification was used to denote the discernable presence in a sample of a contaminant at concentrations estimated as different from the sample blank. A "<" followed by the laboratory's MDL for the contaminant was utilized to denote that a contaminant was detected in a sample at a concentration below the detection limit, but was not quantifiable.*

Table 2c. Inorganic Contaminants (mg/kg) in fish and/or blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay.				
Species	**# Detected/ # Sampled**	**Mean Concentration ± S.D. (Min-Max)**	**Health Assessment Comparison Value (mg/kg)**	**Basis for Comparison Value**
Lead				
Black drum	2/6	0.069 ±0.061 (BDL-0.193)	0.6	EPA IEUBKwin
Gaftopsail catfish	5/14	0.069 ±0.058 (BDL-0.260)		
Red drum	2/6	0.056 ±0.017 (BDL-0.091)		
Southern flounder	2/5	0.111 ±0.099 (ND-0.269)		
Spotted seatrout	5/12	0.077 ±0.039 (BDL-0.164)		
Blue crab	6/12	0.065 ±0.041 (BDL-0.156)		
All species	22/55	0.072 ±0.052 (BDL-0.269)		
Mercury				
Black drum	6/6	0.156 ±0.159 (BDL-0.458)	0.7	ATSDR chronic oral MRL: 0.0003 mg/kg–day
Gaftopsail catfish	14/14	0.294 ±0.155 (BDL-0.566)		
Red drum	6/6	0.072 ±0.029 (BDL-0.110)		
Southern flounder	5/5	0.034 ±0.018 (BDL-0.060)		
Spotted seatrout	12/12	0.113 ±0.036 (0.058-0.196)		
Blue crab	12/12	0.040 ±0.013 (BDL-0.065)		
All Species	55/55	0.136 ±0.137 (BDL-0.566)		
Selenium				
Black drum	6/6	1.014 ±0.180 (0.762-1.216)	6	EPA chronic oral RfD: 0 .005 mg/kg–day ATSDR chronic oral MRL: 0.005 mg/kg–day NAS UL: 0.400 mg/day (0.005 mg/kg–day) RfD or MRL/2: (0.005 mg/kg–day/2= 0.0025 mg/kg–day) to account for other sources of selenium in the diet.
Gaftopsail catfish	12/14	0.253 ±0.209 (ND-0.766)		
Red drum	6/6	0.598 ±0.196 (0.353-0.928)		
Southern flounder	5/5	0.769 ±0.177 (0.488-0.906)		
Spotted seatrout	12/12	0.654 ±0.254 (0.119-0.987)		
Blue crab	11/12	0.551 ±0.250 (ND-1.029)		
All Species	52/55	0.573 ±0.314 (ND-1.216)		

Table 2d. Inorganic contaminants (mg/kg) in fish and/or blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay.

Species	# Detected/ # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (mg/kg)	Basis for Comparison Value
Zinc				
Black drum	6/6	3.985 ±0.764 (2.787-5.135)	700	EPA chronic oral RfD: 0.3 mg/kg–day
Gaftopsail catfish	14/14	10.461 ±5.125 (3.628-20.640)		
Red drum	6/6	4.285 ±0.806 (3.657-5.795)		
Southern flounder	5/5	3.094 ±0.610 (2.444-4.045)		
Spotted seatrout	12/12	4.069 ±2.050 (2.486-9.514)		
Blue crab	12/12	37.947 ±12.811 (3.086-56.008)		
All Species	55/55	13.014 ±15.000 (2.444-56.008)		

Table 3a. Pesticides (mg/kg) in fish and/or blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay.

Species	# Detected / # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (mg/kg)	Basis for Comparison Value
Pentachlorobenzene				
Black drum	0/8	ND	1.867	EPA chronic oral RfD: 0.0008 mg//kg–day
Gaftopsail catfish	8/17	BDL		
Red drum	3/7	BDL		
Southern flounder	0/7	ND		
Spotted seatrout	60/71	0.0005±0.0003 (BDL-0.003)		
Blue crab	1/12	BDL		
All Species	72/122	0.0005±0.0002 (BDL-0.003)		
Hexachlorobenzene				
Black drum	0/8	ND	1.867 0.340	EPA chronic oral RfD: 0.0008 mg//kg–day EPA slope factor 1.6 per mg/kg–day
Gaftopsail catfish	16/17	0.0008±0.0007 (BDL-0.003)		
Red drum	1/7	BDL		
Southern flounder	5/7	BDL		
Spotted seatrout	71/71	0.001±0.002 (BDL-0.012)		
Blue crab	3/12	BDL		
All Species	96/122	0.001±0.002 (BDL-0.012)		
Total Chlordane				
Black drum	7/8	BDL	1.167 1.6	EPA chronic oral RfD: 0.0005 mg//kg–day EPA slope factor 0.35 per mg/kg–day
Gaftopsail catfish	17/17	0.018±0.025 (BDL-0.092)		
Red drum	7/7	0.003±0.001 (BDL-0.006)		
Southern flounder	7/7	BDL		
Spotted seatrout	71/71	0.010±0.012 (BDL-0.069)		
Blue crab	7/12	BDL		
All Species	116/122	0.009±0.014 (BDL-0.092)		

Table 3b. Pesticides (mg/kg) in fish and/or blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay.				
Species	**# Detected / # Sampled**	**Mean Concentration ± S.D. (Min-Max)**	**Health Assessment Comparison Value (mg/kg)**	**Basis for Comparison Value**
2,4' DDE				
Black drum	1/8	BDL	1.167 1.6	EPA chronic oral RfD: 0.0005 mg//kg–day EPA slope factor 0.34 per mg/kg–day
Gaftopsail catfish	1/17	0.001 ±0.0004 (ND-0.003)		
Red drum	0/7	ND		
Southern flounder	2/7	BDL		
Spotted seatrout	22/71	0.001 ±0.0002 (BDL-0.003)		
Blue crab	0/12	ND		
All Species	26/122	0.001 ±0.0002 (BDL-0.003)		
4,4' DDE				
Black drum	8/8	0.002 ±0.002 (BDL-0.005)	1.167 1.6	EPA chronic oral RfD: 0.0005 mg//kg–day EPA slope factor 0.34 per mg/kg–day
Gaftopsail catfish	17/17	0.03±0.04 (0.008-0.168)		
Red drum	7/7	BDL		
Southern flounder	7/7	0.001 ±0.0005 (BDL-0.003)		
Spotted seatrout	71/71	0.008 ±0.007 (BDL-0.034)		
Blue crab	10/12	BDL		
All Species	120/122	0.010 ±0.020 (BDL-0.168)		
4,4' DDD				
Black drum	3/8	BDL	1.167 2.27	EPA chronic oral RfD: 0.0005 mg//kg–day EPA slope factor 0.24 per mg/kg–day
Gaftopsail catfish	17/17	0.006 ±0.007 (BDL-0.022)		
Red drum	6/7	BDL		
Southern flounder	7/7	BDL		
Spotted seatrout	65/71	0.004 ±0.005 (BDL-0.031)		
Blue crab	4/12	BDL		
All Species	102/122	0.004 ±0.005 (BDL-0.031)		

Table 3c. Pesticides (mg/kg) in fish and/or blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay.

Species	# Detected / # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (mg/kg)	Basis for Comparison Value
Mirex				
Black drum	3/8	BDL	0.467	EPA chronic oral RfD: 0.0002 mg//kg–day
Gaftopsail catfish	15/17	0.002±0.0005 (BDL-0.004)		
Red drum	4/7	BDL		
Southern flounder	2/7	BDL		
Spotted seatrout	51/71	BDL		
Blue crab	1/12	BDL		
All Species	76/122	0.002±0.0003 (BDL-0.004)		

Table 4a. PCBs (mg/kg) in fish and/or blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay (presented by species within collection site).

Species	# Detected / # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (mg/kg)	Basis for Comparison Value
Site 1 Pine Gully				
Black drum	2/2	0.011± 0.001 (0.010-0.012)	0.047 0.272	EPA chronic oral RfD: 0.00002 mg/kg–day EPA slope factor: 2.0 per mg/kg–day
Blue crab	2/2	0.010± 0.0006 (0.009-0.010)		
Gaftopsail catfish	3/3	**0.155**[j]± 0.130 (**0.079-0.305**)		
Red drum	1/1	0.027		
Southern flounder	1/1	0.020		
Spotted seatrout	9/9	**0.094**± 0.045 (0.040-**0.189**)		
All Fish, Site 1	16/16	**0.086**± 0.075 (0.011-**0.305**)		
All Species, Site 1	18/18	**0.078**± 0.075 (0.009-**0.305**)		
Site 2 Clifton Beach				
Black drum	1/1	0.010	0.047 0.272	EPA chronic oral RfD: 0.00002 mg/kg–day EPA slope factor: 2.0 per mg/kg–day
Blue crab	2/2	0.010± 0.0003 (0.0096-0.010)		
Gaftopsail catfish	3/3	**0.096**± 0.034 (**0.065-0.132**)		
Southern flounder	2/2	0.011± 0.0001 (0.011-0.012)		
Spotted seatrout	14/14	**0.070**± 0.033 (0.033-**0.149**)		
All Fish, Site 2	20/20	**0.065**± 0.039 (0.010-**0.149**)		
All Species, Site 2	22/22	**0.060**± 0.040 (0.010-**0.149**)		
Site 3 Lone Oak Bayou				
Black drum	1/1	0.010	0.047 0.272	EPA chronic oral RfD: 0.00002 mg/kg–day EPA slope factor: 2.0 per mg/kg–day
Blue crab	2/2	0.010± 0.0003 (0.0096-0.010)		
Gaftopsail catfish	2/2	**0.082**± 0.005 (**0.079-0.086**)		
Red drum	3/3	0.012± 0.002 (0.010-0.014)		
Southern flounder	1/1	0.010		
Spotted seatrout	1/1	0.028		
All Fish, Site 3	8/8	0.031± 0.032 (0.010-**0.086**)		
All Species, Site 3	10/10	0.027± 0.030 (0.010-**0.086**)		

[j] *Emboldened numerals denote concentrations that exceed the HAC value for a compound.*

Table 4b. PCBs (mg/kg) in fish and/or blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay (presented by species within collection site).				
Site 4 Trinity River				
Black drum	1/1	0.024		
Gaftopsail catfish	2/2	**0.065**[j] ± 0.018 (**0.053-0.078**)		
Red drum	1/1	0.016	0.047	EPA chronic oral RfD: 0.00002 mg/kg–day
Southern flounder	1/1	0.010	0.272	EPA slope factor: 2.0 per mg/kg–day
Spotted seatrout	3/3	0.042 ± 0.006 (0.036-**0.048**)		
All Fish, Site 4	8/8	0.038 ± 0.022 (0.010-**0.078**)		
Site 5 HL&P Outfall				
Black drum	1/1	0.013		
Blue crab	4/4	0.009 ± 0.0005 (0.009-0.010)		
Gaftopsail catfish	4/4	**0.125** ± 0.055 (0.045-**0.164**)		
Red drum	1/1	0.019	0.047	EPA chronic oral RfD: 0.00002 mg/kg–day
Southern flounder	1/1	0.010	0.272	EPA slope factor: 2.0 per mg/kg–day
Spotted seatrout	41/41	0.035 ± 0.014 (0.017-**0.083**)		
All Fish, Site 5	48/48	0.041 ± 0.032 (0.010-**0.164**)		
All Species, Site 5	52/52	0.038 ± 0.032 (0.009-**0164**)		
Site 6 Umbrella Point				
Black drum	2/2	0.011 ± 0.001 (0.010-0.012)		
Blue crab	2/2	0.010 ± 0.0006 (0.009-0.010)		
Gaftopsail catfish	3/3	**0.047** ± 0.008 (0.039-**0.054**)		
Red drum	1/1	0.013	0.047	EPA chronic oral RfD: 0.00002 mg/kg–day
Southern flounder	1/1	0.012	0.272	EPA slope factor: 2.0 per mg/kg–day
Spotted seatrout	3/3	**0.062** ± 0.012 (**0.048-0.069**)		
All Fish, Site 6	10/10	0.037 ± 0.024 (0.010-**0.069**)		
All Species, Site 6	12/12	0.033 ± 0.024 (0.009-**0.069**)		

Table 4c. PCBs (mg/kg) in fish and/or blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay (presented by collection site).

All Sites

Black drum	8/8	0.013± 0.005 (0.010-0.024)		
Blue crab	12/12	0.010± 0.0004 (0.009-0.010)		
Gaftopsail catfish	17/17	**0.099**[j]± 0.066 (**0.039-0.305**)		
Red drum	7/7	0.016± 0.006 (0.010-0.027)	0.047	EPA chronic oral RfD: 0.00002 mg/kg–day
Southern flounder	7/7	0.012± 0.004 (0.010-0.020)	0.272	EPA slope factor: 2.0 per mg/kg–day
Spotted seatrout	71/71	**0.051**± 0.032 (0.017-**0.189)**		
All Fish	110/110	**0.051**± 0.044 (0.010-**0.305**)		
All Species	122/122	**0.047**± 0.044 (0.009-**0.305**)		

Table 5a. PCDFs/PCDDs toxicity equivalent (TEQ) concentrations (pg/g) in fish and/or blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay (presented by species and site).

Species	# Detected / # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (pg/g)	Basis for Comparison Value
Site 1 Pine Gully				
Black drum	1/1	0.0011	2.33 3.49	ATSDR chronic oral MRL: 1.0×10^{-9} mg/kg/day EPA slope factor: 1.56×10^{5} per mg/kg/day
Blue crab	2/2	0.0013± 0.0006 (0.0008-0.0017)		
Gaftopsail catfish	3/3	1.9359± 1.5970 (0.9405-**3.7779**[j])		
Red drum	1/1	0.2002		
Spotted seatrout	2/2	**2.3355**± 0.4879 (1.9905-**2.6805**)		
All Fish, Site 1	7/7	1.5257± 1.3685 (0.0011-**3.7779**)		
All Species, Site 1	9/9	1.1869± 1.3625 (0.0008-**3.7779**)		
Site 2 Clifton Beach				
Black drum	1/1	0.0004	2.33 3.49	ATSDR chronic oral MRL: 1.0×10^{-9} mg/kg/day EPA slope factor: 1.56×10^{5} per mg/kg/day
Blue crab	1/2	0.0144± 0.0204 (ND-0.0288)		
Gaftopsail catfish	3/3	1.642± 0.7551 (0.9395-**2.4406**)		
Southern flounder	1/1	0.0006		
Spotted seatrout	2/2	1.2850± 0.1329 (1.1910-1.3790)		
All Fish, Site 2	7/7	1.0711± 0.8680 (0.0004-**2.4406**)		
All Species, Site 2	8/9	0.8363± 0.8844 (ND-**2.4406**)		
Site 3 Lone Oak Bayou				
Black drum	1/1	0.0003	2.33 3.49	ATSDR chronic oral MRL: 1.0×10^{-9} mg/kg/day EPA slope factor: 1.56×10^{5} per mg/kg/day
Blue crab	2/2	0.0008± 0.0007 (0.0003-0.0013)		
Gaftopsail catfish	1/1	1.4237		
Red drum	3/3	0.0340± 0.0580 (0.0003-0.1009)		
Southern flounder	1/1	0.1000		
Spotted seatrout	1/1	0.2804		
All Fish, Site 3	7/7	0.2723± 0.5175 (0.0003-1.4237)		
All Species, Site 3	9/9	0.2120± 0.4639 (0.0003-1.4237)		

Table 5b. PCDF/PCDD toxicity equivalent (TEQ) concentrations (pg/g) in fish and/or blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay (presented by site and species).

Species	# Detected / # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (pg/g)	Basis for Comparison Value
Site 4 Trinity River				
Black drum	1/1	1.0500	2.33 3.49	ATSDR chronic oral MRL: 1.0×10^{-9} mg/kg/day EPA slope factor: 1.56×10^{5} per mg/kg/day
Gaftopsail catfish	2/2	2.0557± 1.209 (1.2009-**2.9105**[j])		
Red drum	1/1	0.0003		
Southern flounder	1/1	0.0400		
Spotted seatrout	2/2	1.3855± 1.6659 (0.2075-**2.5634**)		
All Fish, Site 4	7/7	1.1389± 1.1938 (0.0003-**2.9105**)		
Site 5 HL&P Outfall				
Black drum	1/1	0.1000	2.33 3.49	ATSDR chronic oral MRL: 1.0×10^{-9} mg/kg/day EPA slope factor: 1.56×10^{5} per mg/kg/day
Blue crab	3/4	0.0527± 0.0619 (ND-0.1202)		
Gaftopsail catfish	3/3	**6.1577**± 8.0638 (1.3555-**15.4675**)		
Southern flounder	1/1	0.0204		
Spotted seatrout	3/3	0.7568± 0.6442 (0.3700-1.5004)		
All Fish, Site 5	8/8	2.6080± 5.2365 (0.0204-**15.4675**)		
All Species, Site 5	11/12	1.7562± 4.3628 (ND-**15.4675**)		
Site 6 Umbrella Point				
Black drum	1/1	0.0012	2.33 3.49	ATSDR chronic oral MRL: 1.0×10^{-9} mg/kg/day EPA slope factor: 1.56×10^{5} per mg/kg/day
Blue crab	2/2	0.0881± 0.1125 (0.0086-0.1677)		
Gaftopsail catfish	2/2	0.2153± 0.2993 (0.0036-0.4270)		
Red drum	1/1	0.0002		
Southern flounder	1/1	0.0002		
Spotted seatrout	2/2	0.0518± 0.0305 (0.0302-0.0734)		
All Fish, Site 6	7/7	0.0765± 0.1569 (0.0002-0.4270)		
All Species, Site 6	9/9	0.0791± 0.1416 (0.0002-4270)		

Table 5c. PCDF/PCDD toxicity equivalent (TEQ) concentrations (pg/g) in fish and/or blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay (presented by site).

Species	# Detected / # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (pg/g)	Basis for Comparison Value
All Sites				
Black drum	6/6	0.1922 ± 0.4221 (0.0003-1.0500)		
Blue crab	10/12	0.0350 ± 0.0580 (ND-0.1677)		
Gaftopsail catfish	14/14	**2.5124**[j] ± 3.8544 (0.0036-**15.4675**)		
Red drum	6/6	0.0504 ± 0.0837 (0.0002-0.2002)	2.33	ATSDR chronic oral MRL: 1.0 x 10^{-9} mg/kg/day
Southern flounder	5/5	0.0322 ± 0.0413 (0.0002-0.1000)	3.49	EPA slope factor: 1.56 x 10^{5} per mg/kg/day
Spotted seatrout	12/12	1.0555 ± 0.9698 (0.0302-**2.6805**)		
All Fish	43/43	1.1501 ± 2.4373 (0.0002-**15.4675**)		
All Species	53/55	0.9068 ± 2.1993 (ND-**15.4675**)		

Table 6a. Hazard quotients (HQ's) and hazard indices (HI's) for PCDFs/PCDDs and/or PCBs in fish and/or blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay (presented by species). Table 6a also provides suggested weekly eight-ounce meal consumption rates for 70-kg adults.[k]

Species/Contaminant	Hazard Quotient	Meals per Week
Black Drum		
PCBs	0.28	3.3
PCDDs/PCDFs	0.08	11.2
Hazard Index (meals per week)	0.36 (2.6)	
Blue Crab		
PCBs	0.21	4.3
PCDDs/PCDFs	0.02	61.7
Hazard Index (meals per week)	0.23 (4.0)	
Gaftopsail Catfish		
PCBs	**2.12**[l]	**0.4**
PCDDs/PCDFs	**1.08**	**0.9**
Hazard Index (meals per week)	**3.20 (0.3)**	
Red Drum		
PCBs	0.34	2.7
PCDDs/PCDFs	0.02	42.8
Hazard Index (meals per week)	0.36 (2.5)	
Southern Flounder		
PCBs	0.25	3.6
PCDDs/PCDFs	0.01	67.0
Hazard Index (meals per week)	0.27 (3.4)	
Spotted Seatrout		
PCBs	**1.09**	**0.8**
PCDDs/PCDFs	0.45	2.0
Hazard Index (meals per week)	**1.55 (0.6)**	
All Fish		
PCBs	**1.09**	**0.8**
PCDDs/PCDFs	0.49	1.9
Hazard Index (meals per week)	**1.58 (0.6)**	
All Species		
PCBs	**1.01**	**0.9**
PCDDs/PCDFs	0.39	2.4
Hazard Index (meals per week)	**1.40 (0.7)**	

[k] *DSHS assumes that children under the age of 12 years and/or those who weigh less than 35 kg eat 4-ounce meals.*
[l] *Emboldened numerals denote a HQ or HI or Cancer Risk that exceeds the HAC for that chemical and the suggested meal consumption limit for an adult is less than 1 per week.*

Table 6b. Hazard quotients (HQ's) and hazard indices (HI's) for PCDFs/PCDDs and/or PCBs in fish and/or blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay (presented by species and collection site). Table 6b also provides suggested weekly eight-ounce meal consumption rates for 70-kg adults. [k]

Species/ Contaminant	Hazard Quotient (Meals per Week)					
	Pine Gully	**Clifton Beach**	**Lone Oak Bayou**	**Trinity River**	**HL&P Outfall**	**Umbrella Point**
Black Drum						
PCBs	0.24 (3.9)	0.21 (4.3)	0.21 (4.3)	0.51 (1.8)	0.28 (3.3)	0.24 (3.9)
PCDDs/PCDFs	0.0005 (1962.5)	0.0002 (5396.8)	0.0001 (7195.8)	0.45 (2.1)	0.04 (21.6)	0.0005 (1798.9)
Hazard Index	0.24 (3.9)	0.21 (4.3)	0.21 (4.3)	0.96 (1.0)	0.32 (2.9)	0.24 (3.9)
Hazard Index, All Sites	0.36 (2.6)					
Blue Crab						
PCBs	0.21 (4.3)	0.21 (4.3)	0.21 (4.3)	Blue Crab Not Collected	0.21 (4.3)	0.21 (4.3)
PCDDs/PCDFs	0.0005 (1727.0)	0.006 (149.9	0.0003 (2698.4)		0.02 (40.9)	0.04 (24.5)
Hazard Index	0.21 (4.3)	0.22 (4.2)	0.21 (4.3)		0.24 (3.9)	0.25 (3.7)
Hazard Index, All Sites	0.23 (4.0)					
Gaftopsail Catfish						
PCBs	**3.32 (0.3[l])**	**2.06 (0.4)**	**1.76 (0.5)**	**1.39 (0.7)**	**2.68 (0.3)**	**1.00 (0.9)**
PCDDs/PCDFs	0.83 (1.1)	0.70 (1.3)	0.61 (1.5)	0.88 (1.1)	**2.64 (0.4)**	0.09 (10.0)
Hazard Index	**4.15 (0.2)**	**2.76 (0.3)**	**2.37 (0.4)**	**2.27 (0.4)**	**5.32 (0.2)**	**1.09 (0.8)**
Hazard Index, All Sites	**3.20 (0.3)**					
Red Drum						
PCBs	0.58 (1.6)	Red Drum Not Collected	0.26 (3.6)	0.34 (2.7)	0.41 (2.3)	0.28 (3.3)
PCDDs/PCDFs	0.09 (10.8)		0.01 (63.5)	0.0001 (7195.8)	No Red Drum Samples Analyzed	0.0001 (10793.7)
Hazard Index	0.66 (1.4)		0.27 (3.4)	0.34 (2.7)		0.28 (3.3)
Hazard Index, All Sites	0.36 (2.5)					

Table 6c. Hazard quotients (HQ) and hazard indices (HI) for PCDF/PCDDs and/or PCBs in fish and/or blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay (presented by species and site). Table 6c also provides suggested weekly eight-ounce meal consumption rates for 70-kg adults. [k]

Species/ Contaminant	Hazard Quotient (Meals per Week)					
	Pine Gully	Clifton Beach	Lone Oak Bayou	Trinity River	HL&P Outfall	Umbrella Point
Southern Flounder						
PCBs	0.43 (2.2)	0.24 (3.9)	0.21 (4.3)	0.21 (4.3)	0.21 (4.3)	0.26 (3.6)
PCDDs/PCDFs	No Southern Flounder Samples Analyzed	0.0003 (3597.9)	0.04 (21.6)	0.02 (54.0)	0.009 (107.9)	0.0001 (10793.7)
Hazard Index	0.27 (3.4)	0.24 (3.9)	0.26 (3.6)	0.23 (4.0)	0.22 (4.2)	0.26 (3.6)
Hazard Index, All Sites	0.27 (3.4)					
Spotted Seatrout						
PCBs	**2.01 (0.5)**[l]	**1.50 (0.6)**	0.60 (1.5)	0.90 (1.0)	0.75 (1.2)	**1.32 (0.7)**
PCDDs/PCDFs	**1.00 (0.9)**	0.55 (1.7)	0.12 (7.7)	0.59 (1.6)	0.32 (2.9)	0.02 (41.7)
Hazard Index	**3.01 (0.3)**	**2.05 (0.5)**	0.72 (1.3)	**1.49 (0.6)**	**1.07 (0.9)**	**1.35 (0.7)**
Hazard Index, All Sites	**1.55 (0.6)**					
All Fish						
PCBs	**1.84 (0.5)**	**1.39 (0.7)**	0.66 (1.4)	0.81 (1.1)	0.88 (1.1)	0.79 (1.2)
PCDDs/PCDFs	0.65 (1.4)	0.46 (2.0)	0.12 (7.9)	0.49 (1.9)	**1.11 (0.8)**	0.03 (28.2)
Hazard Index	**2.50 (0.4)**	**1.85 (0.5)**	0.78 (1.2)	**1.30 (0.7)**	**2.00 (0.5)**	0.82 (1.1)
Hazard Index, All Sites	**1.58 (0.6)**					
All Species						
PCBs	**1.67 (0.6)**	**1.29 (0.7)**	0.58 (1.6)	0.81 (1.1)	0.81 (1.1)	0.70 (1.3)
PCDDs/PCDFs	0.80 (1.2)	0.36 (2.6)	0.09 (10.2)	0.49 (1.9)	0.75 (1.2)	0.03 (27.3)
Hazard Index	**2.47 (0.4)**	**1.64 (0.6)**	0.67 (1.4)	**1.30 (0.7)**	**1.57 (0.6)**	0.74 (1.2)
Hazard Index, All Sites	**1.40 (0.7)**					

Table 7a. Theoretical lifetime excess cancer risk from consuming PCDFs/PCDDs, and/or PCBs in fish and blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay (presented by species and contaminant). Table 7a also provides suggested weekly eight-ounce meal consumption rates for 70-kg adults. [k]			
Species/Contaminant	**Theoretical Lifetime Excess Cancer Risk**		**Meals per Week**
	Risk	**1 excess cancer per number exposed**	
Black Drum			
PCBs	4.8E-06	209,402	19.3
PCDDs/PCDFs	5.5E-06	181,583	16.8
Cumulative Theoretical Lifetime Excess Cancer Risk (meals/week)	1.0E-05 (9.0)		
Blue Crab			
PCBs	3.7E-06	272,222	25.1
PCDDs/PCDFs	1.0E-06	996,923	92.1
Cumulative Theoretical Lifetime Excess Cancer Risk (meals/week)	4.7E-06 (19.8)		
Gaftopsail Catfish			
PCBs	3.6E-05	27,497	2.5
PCDDs/PCDFs	7.2E-05	13,891	1.3
Cumulative Theoretical Lifetime Excess Cancer Risk	**1.08E-04**[l]	**9259**	**0.9**
Red Drum			
PCBs	5.9E-06	170,139	15.7
PCDDs/PCDFs	1.4E-06	692,013	63.9
Cumulative Theoretical Lifetime Excess Cancer Risk (meals/week)	7.32E-06 (12.6)		
Southern Flounder			
PCBs	4.4E-06	226,852	21.0
PCDDs/PCDFs	9.2E-07	1,083,860	100.1
Cumulative Theoretical Lifetime Excess Cancer Risk (meals/week)	5.3E-06 (17.3)		
Spotted Seatrout			
PCBs	1.9E-05	53,377	4.9
PCDDs/PCDFs	3.0E-05	33,065	3.1
Cumulative Theoretical Lifetime Excess Cancer Risk (meals/week)	4.9E-05 (1.9)		
All Fish			
PCBs	1.9E-05	53,377	4.9
PCDDs/PCDFs	3.3E-05	30,345	2.8
Cumulative Theoretical Lifetime Excess Cancer Risk (meals/week)	5.2E-05 (1.8)		
All Species			
PCBs	1.7E-05	57,920	5.4
PCDDs/PCDFs	2.6E-05	38,485	3.6
Cumulative Theoretical Lifetime Excess Cancer Risk (meals/week)	4.3E-05 (2.1)		

Table 7b. Theoretical lifetime excess cancer risk from consuming PCDFs/PCDDs and/or PCBs in fish and blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay (presented by species, site, and contaminant) . Table 7b also provides suggested weekly eight-ounce meal consumption rates for 70-kg adults. [k]

Species/ Contaminant	Theoretical Lifetime Excess Cancer Risk (Meals per Week)					
	Pine Gully	**Clifton Beach**	**Lone Oak Bayou**	**Trinity River**	**HL&P Outfall**	**Umbrella Point**
Black Drum						
PCBs	4.0E-06 (22.9)	3.7E-06 (25.1)	3.7E-06 (25.1)	8.8E-06 (10.5)	4.8E-06 (19.3)	4.0E-06 (22.9)
PCDDs/PCDFs	3.2E-08 (2,931.1)	1.1E-08 (8,060.7)	8.6E-09 (10,747.5)	3.0E-05 (3.1)	2.9E-06 (32.2)	3.4E-08 (2,686.9)
Cumulative Excess Cancer Risk	4.1E-06 (22.7)	3.7E-06 (25.1)	3.7E-06 (25.1)	3.9E-05 (2.4)	7.6E-06 (12.1)	4.1E-06 (22.7)
Cumulative Excess Cancer Risk, All Sites	1.0E-05 (9.0)					
Blue Crab						
PCBs	3.7E-06 (25.1)	3.7E-06 (25.1)	3.7E-06 (25.1)	Blue Crab Not Collected	3.7E-06 (25.1)	3.7E-06 (25.1)
PCDDs/PCDFs	3.6E-08 (2,579.4)	4.1E-07 (223.9)	2.3E-08 (4,030.3)		1.5E-06 (61.1)	2.5E-06 (36.6)
Cumulative Excess Cancer Risk	3.7E-06 (24.9)	4.1E-06 (22.6)	3.7E-06 (25.0)		5.2E-06 (17.8)	6.2E-06 (14.9)
Cumulative Excess Cancer Risk, All Sites	4.7E-06 (19.8)					
Gaftopsail Catfish						
PCBs	5.7E-05 (1.6)	3.5E-05 (2.6)	3.0E-05 (3.1)	2.4E-05 (3.9)	4.6E-05 (2.0)	1.7E-05 (5.4)
PCDDs/PCDFs	5.5E-05 (1.7)	4.7E-05 (1.1)	4.1E-05 (2.3)	5.9E-05 (1.6)	**1.8E-04 (0.5)**	6.2E-06 (15.0)
Cumulative Excess Cancer Risk	**1.12E-04 (0.8)**[l]	8.2E-05 (1.1)	7.1 E-05 (1.3)	8.3E-05 (1.1)	**2.2E-04 (0.4)**	2.3E-05 (3.9)
Cumulative Excess Cancer Risk, All Sites	**1.08E-04 (0.9)**					
Red Drum						
PCBs	9.9E-06 (9.3)	Red Drum Not Collected	4.4E-06 (21.0)	5.9E-06 (15.7)	7.0E-06 (13.2)	4.8E-06 (19.3)
PCDDs/PCDFs	5.7E-06 (16.1)		9.7E-07 (94.9)	8.6E-09 (10,747.5)	No red drum samples	5.7E-09 (16,121.3)
Cumulative Excess Cancer Risk	1.6E-05 (5.9)		5.4E-06 (17.2)	5.9E-06 (15.7)	7.0E-06 (19.3)	4.8E-06 (19.3)
Cumulative Excess Cancer Risk, All Sites	7.32E-06 (12.6)					

Table 7c. Theoretical lifetime excess cancer risk from consuming PCDFs/PCDDs, and/or PCBs in fish and blue crab collected in 2006 from Trinity Bay and Upper Galveston Bay (presented by species, site, and contaminant(s)). Table 7c also provides suggested weekly eight-ounce meal consumption rates for 70-kg adults. [k]

Species/ Contaminant	Theoretical Lifetime Excess Cancer Risk (Meals per Week)					
	Pine Gully	**Clifton Beach**	**Lone Oak Bayou**	**Trinity River**	**HPL Outfall**	**Umbrella Point**
Southern Flounder						
PCBs	7.3E-06 (12.6)	4.0E-06 (22.9)	3.7E-06 (25.1)	3.7E-06 (25.1)	3.7E-06 (25.1)	4.4E-06 (21.0)
PCDDs/PCDFs	No Southern Flounder Samples	1.7E-08 (5,373.8)	29.E-06 (32.2)	1.1E-06 (80.6)	5.7E-07 (161.2)	5.7E-09 (16,121.3)
Cumulative Excess Cancer Risk	7.3E-06 (12.6)	4.1E-06 (22.8)	2.9E-06 (14.1)	4.8E-06 (19.2)	4.3E-06 (21.8)	4.4E-06 (21.0)
Cumulative Excess Cancer Risk, All Sites	5.3E-06 (17.3)					
Spotted Seatrout						
PCBs	3.5E-05 (2.7)	2.6E-05 (3.6)	1.0E-05 (9.0)	1.5E-05 (6.0)	1.3E-05 (7.2)	2.3E-05 (4.1)
PCDDs/PCDFs	6.7E-05 (1.4)	3.7E-05 (2.5)	8.0E-06 (11.5)	4.0E-05 (2.3)	2.2E-05 (4.3)	1.5E-06 (62.2)
Cumulative Excess Cancer Risk	**1.0E-04 (0.9[l])**	6.3E-05 (1.5)	1.8E-05 (5.0)	5.5E-05 (1.7)	3.5E-05 (2.7)	2.4E-05 (3.8)
Cumulative Excess Cancer Risk, All Sites	4.9E-05 (1.9)					
All Fish						
PCBs	3.2E-05 (2.9)	2.4E-05 (3.9)	1.1E-05 (8.1)	1.4E-05 (6.6)	1.5E-05 (6.1)	1.4E-05 (6.8)
PCDDs/PCDFs	4.4E-05 (2.1)	31.E-05 (3.0)	7.8E-06 (11.8)	3.3E-05 (2.8)	7.5E-05 (1.2)	2.2E-06 (42.1)
Cumulative Excess Cancer Risk	7.5E-05 (1.2)	5.5E-05 (1.7)	1.9E-05 (4.8)	4.7E-05 (2.0)	9.0E-05 (1.0)	1.6E-05 (5.9)
Cumulative Excess Cancer Risk, All Sites	5.2E-05 (1.8)					
All Species						
PCBs	2.9E-05 (3.2)	2.2E-05 (4.2)	9.9E-06 (9.3)	1.4E-05 (6.6)	1.4E-05 (6.6)	1.2E-05 (7.6)
PCDDs/PCDFs	5.4E-05 (1.7)	2.4E-05 (3.9)	6.1E-06 (15.2)	3.3E-05 (2.8)	5.0E-05 (1.8)	2.3E-06 (40.8)
Cumulative Excess Cancer Risk	8.2E-05 (1.1)	4.6E-05 (2.0)	1.6E-05 (5.8)	4.7E-05 (2.0)	6.4E-05 (1.4)	1.4E-05 (6.4)
Cumulative Excess Cancer Risk, All Sites	4.3E-05 (2.1)					

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