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

Lower Galveston Bay

Chambers, Galveston, and Harris Counties, Texas

June 2008

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Division for Regulatory Services
Policy, Standards, and Quality Assurance Unit
Seafood and Aquatic Life Group

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. 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; EPA) 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*,[12] the EPA conducted a one-time nationwide survey of contaminant residues in fish. In the report of that evaluation of fish-borne contaminants, the EPA described 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.[13]

In 1990, the DSHS – in its first detailed evaluation of the Texas sites reported in 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 to the north of a line

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

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 [any species of] catfish and/or blue crab to no more than one eight-ounce 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 [any] 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 funded the DSHS 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/Ds. Results from the *NCWG* study showed what could have been a slight decrease in average PCDF/D 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 species and blue crab should continue unchanged. Again, the DSHS continued ADV-3 in its original form.

Between 1997 and 2000, the USEPA indirectly funded three grants to the DSHS for study of the Galveston Bay system. (1) “The USEPA Children’s Uses of Galveston Bay" grant; (2) a Texas Commission on Environmental Quality (TCEQ)[b] Total Maximum Daily Load (TMDL) program grant and (3) a grant from the Galveston Bay Estuary Program (GBEP)[15] allowed the DSHS to more comprehensively evaluate chemical contaminants in fish and shellfish from the Galveston Bay system. During these studies, 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 surveyed the Christmas Bay system (Bastrop, Christmas, and Drum Bays), Clear Creek (for which ADV-7 was issued in 1993), and Clear Lake.

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

The Galveston Bay studies conducted from 1997 to 2000 revealed that – with few exceptions – fish and blue crab from the Christmas Bay system, East Bay, West Bay, Lower Galveston Bay, Trinity Bay, Clear Creek, and Clear Lake showed little evidence of contamination with pollutants capable of causing adverse human health effects. None of these contaminants exceeded the health-based assessment comparison values (HAC values) DSHS used at the time to evaluate the likelihood of adverse human health effects from consumption of chemically contaminated fish and shellfish. The DSHS concluded from these investigations that eating fish and blue crab from the named portions of the Galveston Bay system posed no apparent public health hazard. Furthermore, on October 9, 2001, as a direct result of these studies – which showed that fish and shellfish from Clear Creek no longer contained chemical contaminants at levels likely to pose an apparent human health hazard, the DSHS rescinded the 1993 advisory (ADV-7) that had suggested no consumption of any fish or blue crab taken from Clear Creek.[16]

On the other hand, the same studies (1997-2000) yielded other data that prompted the DSHS to modify ADV-3. That modification, embodied in Advisory 20 (ADV-20), extended ADV-3 to 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 blue crab or any fish species from the Houston Ship Channel upstream of the Lynchburg Ferry crossing and 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 had established the National Estuary Program (NEP) to promote long-term planning and management of nationally significant estuaries.[18] Early on, the NEP identified 28 nationally significant estuaries, of which Galveston Bay was one (the other Texas estuary identified by the NEP was the Coastal Bend Bays and Estuaries system). The Galveston Bay Estuary Program (GBEP), formed as a state-supported program from the NEP in 1989, is one of two such programs in Texas. [19] The GBEP is a non-regulatory program administered by the TCEQ. 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. The GBEP has enhanced water quality through promotion of reduction of pollutants in bayous, creeks, and Galveston Bay, and has established a seafood-safety monitoring program to assist the state 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 constituted 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 monitoring program.

The results of the 2004 characterization of health risks of consuming 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. Those results also revealed that spotted seatrout contained polychlorinated biphenyls (PCBs) at levels 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 recommended 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 its 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 were nursing, pregnant, or who may have become pregnant were advised not to consume spotted seatrout from these waters.[20] As of this time, ADV-28 is still in force.

The 2004 risk characterization also recommended additional fish tissue monitoring to determine if spotted seatrout collected from the Galveston Bay system contain PCBs at concentrations of concern to public health. Tagging data from the Texas Parks and Wildlife Department (TPWD) indicate that spotted seatrout tend to move around 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 system.

The present report summarizes an evaluation of fish and blue crab collected in 2006 and 2007 from Lower Galveston Bay south 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 demonstrates progress in developing 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; 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 2006-2007 Lower Galveston Bay Sample Set

Between October 2006 and May 2007, SALG staff collected 72 fish and 10 composite blue crab samples from Lower Galveston Bay. Risk assessors used data from these fish and shellfish to assess the potential for adverse human health outcomes from consuming fish from the bay. To provide spatial coverage of the study area (Figure 1), the SALG selected 10 sites. Site 1 was located near Hanna Reef, Site 2 near the Bolivar Spoil Island, Site 3 at Campbell Bayou, Site 4 near Snake Island, Site 5 near Dollar Point, and Site 6 near Redfish Island. Site 7 was located at the Galveston Jetties, Site 8 near the Pelican Island Bridge, Site 9 in Offat's Bayou, and Site 10 at Moses Lake. Species collected represent distinct ecological groups (i.e. predators and bottom-dwellers) that have some potential to bioaccumulate chemical contaminants, have a wide geographic distribution, are of local recreational fishing value, and/or that anglers commonly consume. The 72 fish and 10 blue crab collected from Lower Galveston Bay represented all targeted species. Table 1 lists species in descending order by number of samples collected: spotted seatrout (47), blue crab (10), gaftopsail catfish (7), black drum (6), red drum (6), and southern flounder (6).

The survey team set gill nets and blue crab traps at sampling sites 1 through 6 in late afternoon (Figure 1; the team did not set gill nets at sites 7 through 10), 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 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 with spotted seatrout gill net catch rate averaging fewer than one spotted seatrout per net per night (0 = 0.5 seatrout/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. The survey team fished sites 7-10 only for spotted seatrout. These additional sites were selected to expand the collection area and increase catch.

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, the survey team combined four to eight eviscerated whole blue crab bodies to produce each composite blue crab sample.

To ensure that cross-sample contamination did not occur, the team changed the cutting board foil and rinsed the fillet knife with distilled water after processing each sample (whether crab or fish). Wrapping each in two layers of clean aluminum foil, team members placed samples into separate, unused, pre-labeled plastic freezer bags, 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 team members.

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 arrival of the samples at the laboratory, GERG personnel notified the SALG of receipt of the 82 Lower Galveston 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 Lower Galveston Bay for many 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/Ds). The laboratory analyzed all 82 samples for metals, pesticides, and PCBs as well as a subset of 16 of the original 82 samples for PCDFs/PCDD, 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 fish of legal size for possession in Texas serves well as a surrogate for methylmercury concentration in fish. Historically, methylmercury analyses are difficult to perform accurately and the test is more expensive than analysis of total mercury. The USEPA, therefore, recommends that states determine total mercury in fish. To protect human health, however, the USEPA also advises that states assume 100% of the mercury measured in each fish or shellfish is methylmercury. Therefore, following USEPA guidance, the SALG requested and received total mercury analyses of fish and blue crab tissues. The DSHS compares total mercury concentrations to a comparison value derived from the Agency for Toxic Substances and Disease Registry's (ATSDR) minimal risk level for methylmercury toxicity[27] (in it's risk characterizations, 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 the EPA 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]

Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans (PCDFs/Ds)

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.[33, 34]
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 equipotent 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.[35]

$$\text{Total TEQs} = \overset{n}{\underset{i=1}{?}} (CI \times TEF)$$

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.[36] 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.[36] 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.[37] 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)[38] or the Agency for Toxic Substances and Disease Registry's (ATSDR) chronic oral minimal risk levels (MRLs).[39] 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.*[40]

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.*[40]

The ATSDR uses a similar technique to derive its MRLs.[39] 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).*[41]

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.[39]

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.[38.,40] 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. [40, 42]

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)[40] 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. [43,44] 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.[45] 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.[46] 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.[38] Additionally, in accordance with the ATSDR's *Child Health Initiative*[47] and the EPA's *National Agenda to Protect Children's Health from Environmental Threats,*[48] 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.

Data Analysis and Statistical Methods

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.[49] In computing descriptive statistics, SALG risk assessors utilized ½ the detection limit for analytes designated as not detected (ND) or estimated (J)[c]. However, in the present evaluation of PCDF/D computations, the SALG employed estimated J concentrations as reported and assumed that values designated "ND" were zero to avoid inflating PCDF/D concentrations. The SALG used the descriptive statistics from the above manipulations to generate the present report. 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 Lower Galveston Bay.[50] 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).[51, 52]

RESULTS

The GERG laboratory completed analyses and electronically transmitted the results to the SALG at the DSHS in April 2008. The laboratory reported the analytical results for metals, pesticides and PCBs (82 samples), PCDFs/Ds, semivolatile organic compounds (SVOCs) and volatile organic compounds (VOCs; 16 samples).

For reference, Table 1 contains the samples organized by collection site. Tables 2, 3, 4, and 5 contain summary results of metals, pesticides, PCBs, and PCDFs/Ds respectively, in fish and blue crab collected between October 2006 and May 2007 from Lower Galveston Bay. Tables 2a through 2d present results of metals analyses. Table 3a contains pesticide data. Tables 4a through 4c outline summary statistics for PCBs; Tables 5a through 5b summarize PCDF/D data. The paper does not display SVOC and VOC data. Unless otherwise stated, table summaries present the number of samples containing a specific toxicant/number tested, the mean concentration ± 1 standard deviation (68% of samples should fall within one standard deviation of the arithmetic

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[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.*

mean in a sample from a normally-distributed population), and, in parentheses under the mean and standard deviation, the minimum and the maximum detected concentrations. Those who prefer to see the range may derive this statistic by subtracting the minimum concentration of a given toxicant from its maximum concentration. In the tables, results may be given as "ND" (not detected), BDL (below detection limit), or as measured concentrations. Samples with results given as BDL rely upon the laboratory's method detection limit (MDL), defined as the minimum concentration of an analyte of interest that can be measured and reported with 99% confidence that the analyte concentration is greater than zero.

Inorganic Contaminants

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

The laboratory reported all seven inorganic or metallic constituents (arsenic cadmium, copper, lead, mercury, selenium, and zinc) present in fish and blue crab samples from Lower Galveston Bay. Eighty-two of 82 samples contained arsenic at measurable levels (Table 2a). Total arsenic was significantly higher in bottom feeders than in predators (2-tailed t-test for independent groups of unequal size and assuming unequal variance: mean arsenic in bottom feeders = 1.616 mg/kg, n=59; mean arsenic in predators=0.406 mg/kg; n=23. t=6.066, df = 22.96, p<0001). Cadmium was present in nine of 82 samples at concentrations ranging from 25% to 38% of the $\mathrm{HAC}_{\mathrm{nonca}}$ for this element. Cadmium occurred at measurable levels only in blue crab (0=0.018 mg/kg). Across all species, the average concentration of cadmium was 0.012 mg/kg. All samples also contained copper (Table 2b). Mean copper concentration in all species combined was 1.451±3.160 mg/kg. Copper in blue crab was much higher than in other species (Table 2b). Nonetheless, copper occurred in each species at very low levels; all were well below the $\mathrm{HAC}_{\mathrm{nonca}}$ (333 mg/kg). Lead was detected in all samples (Table 2c) at relatively low levels with 76/82 samples (93%) containing estimates of lead concentrations (J-values). All fish and blue crab contained mercury. The mean mercury concentration among species was 0.101±0.087 mg/kg (Table 2c). A red drum contained the highest reported concentration of mercury (0.556 mg/kg). No sample contained mercury at a concentration above the mercury $\mathrm{HAC}_{\mathrm{nonca}}$ (0.7 mg/kg). All samples also contained selenium. The mean selenium concentration in all species was 0.697±0.223 mg/kg (Table 2c). In contrast to other species, gaftopsail catfish averaged only 0.218 mg/kg. Zinc was present in all species; the average concentration of zinc in combined species was 6.619±10.075 mg/kg (Table 2d). Blue crab contained the highest average zinc concentration (31.541 ± 3.477 mg/kg) followed by zinc in red drum (7.875 ± 12.789 mg/kg) and gaftopsail catfish (5.052 ± 1.549 mg/kg). The species containing the lowest average concentration of zinc was southern flounder, at 2.462±0.505 mg/kg. The $\mathrm{HAC}_{\mathrm{nonca}}$ for zinc is 700 mg/kg.

Organic Contaminants

Pesticides

The GERG laboratory analyzed all fish and blue crab for 34 pesticides. Trace[d] quantities of 1,2,3,4-tetrachlorobenzene, 1,2,4,5-tetrachlorobenzene, alpha hexachlorocyclohexane (alpha HCH), pentachloroanisole, pentachlorobenzene, mirex, 2,4'-DDE, 2,4'-DDD, diazinon, dacthal, endosulfan I, and methoxychlor were present in some fish and blue crab samples (data not presented). Sixty-five of 82 samples contained very low concentrations of hexachlorobenzene (data not presented). Fifty-nine of the 65 samples containing hexachlorobenzene had only estimated concentrations (J-values). One spotted seatrout contained a trace (0.004 mg/kg) of gamma HCH (lindane). Thirty-eight of 82 samples contained low levels of dieldrin (data not shown). Eleven of 38 dieldrin-positive samples contained measurable dieldrin while 27 contained dieldrin at levels below the laboratory's MDL (estimated or J values). Six of 82 samples contained some malathion (data not presented), three of which concentrations were estimated concentrations (J-values). The GERG laboratory reported measurable concentrations of endosulfan II in three of 82 samples (data not presented); three other samples contained traces of endosulfan II reported as estimates or J-values (data not presented).

Table 3 shows that seventy-four of 82 fish and blue crab samples contained low levels of compounds consistent with technical chlordane (mean concentration = 0.003±0.002 mg/kg). Some gaftopsail catfish and spotted seatrout contained chlordane at measurable, but minute concentrations (Table 3a). Sixty-three of 82 samples contained chlordane at concentrations below the laboratory's MDL (estimates of concentrations). Black drum, red drum, southern flounder, and blue crab samples contained only estimable concentrations of chlordane. A spotted seatrout contained the highest concentration of chlordane (0.011 mg/kg).

As shown in Table 3 all 82 samples contained some level of 4,4'-DDE (0=0.005±0.005 mg/kg), 43 of which – including some black drum, gaftopsail catfish, southern flounder, and spotted seatrout – contained measurable 4,4'-DDE. Thirty-nine samples, including blue crab and red drum, had only estimated concentrations of 4,4'-DDE (Table 3). A gaftopsail catfish contained the highest concentration of 4,4'-DDE (0.026 mg/kg). Seventy samples contained 4,4'-DDD at estimated concentrations (data not presented) while two of 82 samples contained measurable but very low concentrations of 4,4'-DDD (data not presented).

PCBs

For the Lower Galveston Bay, the present study marks the first instance of sample analysis for PCB congeners instead of Aroclors®. Thus, direct comparison of PCB concentrations from this report with Aroclors® reported in previous studies of the Galveston Bay system would be inappropriate.

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[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.*

Tables 4a, 4b, and 4c contain summary statistics – by site and by species – for PCBs measured in fish and blue crab samples collected in 2006 and 2007 from Lower Galveston Bay. The laboratory analyzed all samples for all 209 PCB congeners. Seventy-two fish and eight blue crab contained one or more measurable PCB congeners (80/82 samples; Table 4c). No sample contained all PCB congeners (data not shown). Tagging data from the TPWD show that spotted seatrout move throughout the bay system (data not shown). TPWD and the SALG also suspect that other fish species also move about the bay. Thus, SALG risk assessors compared average PCB concentrations in each species with the PCB HAC values as well as comparing PCB concentration in combined species, but did not compare PCBs in species at each collection site (to see whether PCB concentrations in each species were affected by collection site). Nonetheless, the SALG paper presents site and species specific PCB concentrations.

Table 4c shows summary statistics for PCBs in each species of fish and in blue crab samples without regard to collection site. Thus, looking at data from Table 4c one can compare PCB concentration in each species without regard to collection site. One can also see the average concentration of PCBs in all species combined, again without regard to collection site. These data showed gaftopsail catfish to contain the highest average PCB concentration (0.097 ± 0.014 mg/kg), followed by spotted seatrout (0.040±0.030 mg/kg). Black drum and blue crab contained the lowest average concentrations of PCBs. Both species coincidentally contained an average 0.011 mg/kg.

PCDFs/Ds

Summary statistics for PCDFs/Ds measured in fish and blue crab samples collected in 2006 and 2007 from Lower Galveston Bay are in Tables 5a and 5b. The laboratory analyzed a subset of 16 of the original 82 fish and blue crab samples for 17 of a possible 210 congeners of PCDF/D (135 PCDFs + 75 PCDDs). SALG risk assessors requested analysis of PCDF/D congeners that have chlorine substituted for hydrogen at the 2, 3, 7, and 8 carbon positions of the dibenzofuran or dibenzo-*p*-dioxin nucleus (10 PCDFs and 7 PCDDs). These 17 congeners of PCDF/D are those reported to show adverse human health effects.[53] Although 12 of 209 PCB congeners – those often referred to as "coplanar PCBs," meaning the molecule can assume a flat configuration with both rings lying in the same plane – may also have dioxin-like toxicity, the SALG does not assess co-planar PCBs for these qualities because researchers have not reported extensive evaluations of those twelve PCBs. In Tables 5a and 5b, for the convenience of readers interested in site- and species-specific concentrations of PCDFs/Ds in fish, the SALG shows PCDF/D concentrations in each species at each site.

Before generating summary statistics for PCDFs/Ds, the SALG risk assessors converted the reported concentration of each PCDF or PCDD congener reported present in a tissue sample to a concentration equivalent in toxicity to that of 2,3,7,8-TCDD (a TEQ concentration - expressed as pg/g or ng/kg). Summary statistics revealed twelve of 16 samples (11 fish and 1 blue crab; Table 5b) analyzed for PCDFs/Ds contained one or more of the 17 congeners of interest to risk assessors at the SALG (minimum – to – maximum concentration after conversion: ND-3.4839 pg/g – or ng/kg). No samples contained all 17 congeners (data not shown). Gaftopsail catfish contained the highest mean TEQ concentration (0=1.3986 ± 1.5510 pg/g – or ng/kg), followed by spotted seatrout (0 ± S.D = 0.9811±1.4451 pg/g –or ng/kg). Four samples (three fish, one blue crab) analyzed for PCDFs/Ds contained no identifiable PCDFs/Ds (Table 5b) as indicated by the acronym "ND" for "not detected." As with PCBs, risk assessors compared PCDFs/Ds to their HAC values without regard to collection site.

SVOCs

The GERG laboratory analyzed the same 16 samples for SVOCs as were examined for PCDFs/Ds. The GERG laboratory reported only sporadic occurrences or low concentrations of specific SVOCs in the 14 fish and 2 blue crab samples collected in 2006 and 2007 from Lower Galveston Bay (data not presented). For example, bis (2-ethylhexylphthalate or, alternatively, di-(2-ethylhexyl) phthalate; DEHP), a plasticizer ubiquitous in the environment, was present in all 16 samples, 15 of which samples contained only trace quantities (BDL) of DEHP; one sample contained a low but measurable quantity of the plasticizer. One blue crab contained a trace of diethylphthalate (DEP). The GERG laboratory also reported traces of acenaphthene, fluorene, and di-n-butyl phthalate (DBP) in some of the 16 samples. No other SVOCs were reported present in fish or blue crab collected in 2006 and 2007 from Lower Galveston Bay.

VOCs

The laboratory analyzed the same 16 samples for VOCs as were examined for PCDFs/Ds and SVOCs. Although these data were not presented, all samples contained carbon disulfide (0.0056 mg/kg – 0.186 mg/kg), methylene chloride (0.037 mg/kg – 1.931 mg/kg), and toluene (0.003 mg/kg –0.066 mg/kg). Fourteen samples contained acetone (seven of the 14 were estimated (J-value) concentrations). Benzene occurred at low levels in 14 samples (maximum concentration: 0.002 mg/kg). Twelve samples contained low levels of naphthalene (maximum concentration: 0.083 mg/kg). Twelve samples contained trace quantities of 1,2- dichloroethane. Chloromethane occurred at low concentrations in 11 samples as did 1,4- dichlorobenzene (maximum concentration: 0.016 mg/kg) and chlorobenzene. Difluorochloromethane, and butylbenzene occurred sporadically and at low concentrations. To reiterate, VOCs in samples collected in 2006-2007 from Lower Galveston Bay generally occurred only at very low levels, with many estimated concentrations (J-values) and, as often occurs, 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 in actual risk may depend upon factors such as the use of animal instead of human studies, use of subchronic rather than chronic studies, interspecies variability, intra-species variability, and database insufficiency. 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 the study chosen as the "critical" one, the species/strain of animal used in the critical study, the target organ selected as the "critical organ," exposure periods, exposure route, doses, or uncontrolled variations in other conditions.[38] Despite such 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 Lower Galveston Bay. Conclusions and recommendations predicated upon the stated goal of the DSHS to protect human health follow the discussion of the relevance of findings to risk.

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

Inorganic Contaminants

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

Almost all arsenic in finfish appears as organic arsenic with approximately 10% of arsenic in fish likely occurring as inorganic arsenic.[25] Table 2a gives both total arsenic as measured and the inorganic arsenic concentration in each species calculated from total arsenic. In this sample of fish and blue crab from Lower Galveston Bay, black drum contained the highest average calculated concentration of inorganic arsenic (0.205 mg/kg), a concentration that did not exceed HAC values for inorganic arsenic. The overall average concentration of arsenic in all species collected from Lower Galveston Bay in 2006 and 2007 was 0.745 mg/kg. No finfish species contained inorganic arsenic at a calculated concentration that exceeded the HAC_{nonca} for inorganic arsenic in fish and shellfish.

Six blue crab of ten from Lower Galveston Bay (Table 2b) contained measurable cadmium; neither the average value of cadmium in blue crab samples nor any single cadmium concentration in blue crabs exceeded the HAC_{nonca} for cadmium. Red drum and spotted seatrout contained detectable, but not measurable cadmium (indicated by the acronym BDL – "below detection limit"). Black drum, gaftopsail catfish, and southern flounder contained no detectable cadmium (ND).

Eighty-two of 82 samples collected in 2006-2007 from Lower Galveston Bay contained copper; the average copper concentration in all samples was 1.451 ± 3.160 mg/kg, a concentration far below the HAC_{nonca} for copper in fish or shellfish (333 mg/kg). In no single sample did copper concentration approach the HAC_{nonca} for this essential trace element. Thus, consumption of copper in fish or blue crab from Lower Galveston Bay is unlikely to result in adverse human health outcomes.

All 82 samples contained inorganic lead. Concentrations were low – in the neighborhood of 10% of the HAC_{nonca} (0.6 mg/kg) for lead. The HAC_{nonca} for inorganic lead, developed with the USEPA's IEUBK model, is fundamentally different from other HAC_{nonca} values. The HAC_{nonca} for inorganic lead in fish or shellfish is a concentration that – if the fish or shellfish is consumed by a child whose PbB is at or near 10 mcg/dL – could cause that child's PbB level to exceed the Centers of Disease Control and Prevention's (CDC) published children's blood lead level (PbB) of concern (10 mcg/dL). The HAC_{nonca} for lead, on the other hand, is a concentration of inorganic lead in fish or shellfish that, if consumed, is unlikely to result in adverse health effects over a lifetime. Inorganic lead is a neurotoxicant in fetuses, children, and – at high levels – in adults.[36] In children, inorganic lead in blood at levels much lower than 10 mcg/dL have reportedly been associated with subtle neurotoxicity.[51,52] As of this writing, no researchers have reported finding a threshold for neurotoxic effects of lead on children's central nervous system (CNS) development and function; further, both remote and recent reports question the existence of such a threshold. Nonetheless, the CDC elected to retain its long-ago chosen level of concern for children's blood lead levels because "arbitrary" reduction in the level of concern "could be a capricious decision."[51,52] Nonetheless, inorganic lead in fish and blue crab from Lower Galveston Bay are unlikely to contribute materially to the average child's body burden of lead because lead did not exceed the HAC_{nonca} for this toxic metalloid (Table 2c). Thus, the DSHS concludes that consumption of lead-containing fish or blue crab from Lower Galveston Bay is not likely to negatively affect children's health, or for that matter, the health of adults.

Mercury in fish (methylmercury) is a known fetal neurotoxicant that readily reaches the fetal brain through the maternal-fetal circulation. It is important in this context 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 and the fetus.[54] The HAC_{nonca} value for methylmercury in fish or shellfish – based on the neurodevelopmental effects of methylmercury –has, in Texas, been set by the DSHS to 0.7 mg/kg, derived from the ATSDR's methylmercury-based MRL of 0.0003 mg/kg –day.[55] All 82 samples contained mercury. The highest mercury concentration occurred in a red drum (0.556 mg/kg). The average concentration of mercury in all samples was approximately 1/7 the HAC_{nonca} value for methylmercury; Table 2c). No sample contained mercury in excess of the HAC_{nonca} value so the DSHS concludes that consumption of mercury in fish and blue crab from Lower Galveston Bay will not likely adversely affect human neurocognitive health.

Selenium and zinc (Table 2c and 2d) were present in all 82 samples. Selenium was reported at an average concentration approximately 1/10 the HAC_{nonca} for this element (6 mg/kg). Zinc was present at levels far below the HAC_{nonca} (700 mg/kg), The DSHS concludes that consumption of fish or shellfish from Lower Galveston Bay containing copper, selenium, or zinc is quite unlikely to result in adverse systemic health effects. More likely, the presence of copper, selenium, and/or zinc in fish and shellfish from Lower Galveston Bay will supplement other dietary sources of these three elements, so essential for normal bodily functions in humans and in many other species.[56]

Organic Contaminants

Pesticides

The laboratory reported very low to trace levels of a number of pesticides (most of them chlorinated varieties) in fish and blue crab samples from Lower Galveston Bay. Among these pesticides were pentachlorobenzene, hexachlorobenzene, technical chlordane, various DDT derivatives, dieldrin, endosulfans, pentachloroanisole, and mirex. Almost all pesticides occurred at levels near the MDL. No pesticide in fish or blue crab samples occurred at a concentration approaching or exceeding its HAC_{nonca} value. Consumption of fish or blue crab from Lower

Galveston Bay containing traces of one or more of these pesticides would not likely result in adverse human health effects.

SVOCs

SVOCs were of no particular significance in the sixteen samples selected for SVOC analysis from the 82 samples collected in 2006 and 2007 from Lower Galveston Bay. The laboratory estimated concentrations (J-values) of the plasticizer bis (2-ethylhexyl) phthalate in all samples (one sample had a measurable level of DEHP) and, in some samples, estimated concentrations of di-n-butyl phthalate. A trace of diethylphthalate was observed in one blue crab. Acenaphthene and fluorine occurred sporadically. No SVOCs in the present samples exceeded its HAC_{nonca} (data not presented). At the very low levels observed in fish or blue crab samples, consumption would not likely result in adverse human health outcomes.

VOCs

Most, if not all, of the 16 samples from Lower Galveston Bay analyzed for VOCs contained acetone, methylene chloride, and 1,2-dichloroethane, all of which are likely post-collection contaminants or products of necrosis. Benzene, chlorobenzene, 1,2 dichlorobenzene, toluene, and naphthalene were also observed at trace to very low levels in most, if not all the 16 samples. No SVOC exceeded its HAC_{nonca} value. Thus, taken alone, consumption of low levels of the observed VOCs should not cause adverse systemic health effects in humans if consumed in fish or blue crab from Lower Galveston Bay.

PCBs

The GERG laboratory analyzed PCBs in all 82 samples of fish or blue crab collected in 2006 - 2007 from Lower Galveston Bay. All samples contained one or more of the possible 209 PCB congeners (Tables 4a, 4b, and 4c). 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 bay 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 or 2007 from Lower Galveston Bay (listed beneath the mean and standard deviation). Although all fish and eight of 10 blue crab samples contained PCBs (Tables 4a, 4b, and 4c), only gaftopsail catfish, with an average PCB concentration of 0.097±0.014 mg/kg (almost twice the HAC_{nonca}) contained PCBs at concentrations in excess of the HAC_{nonca} value (0.047 mg/kg). PCB concentrations in species other than gaftopsail catfish averaged only 25% to 34% of the HAC_{nonca} for these contaminants.

Using only the 43 congeners of PCBs utilized by other investigators,[28][29] the SALG risk assessors calculated HQs to assess the likelihood (possibility) that the critical adverse effect would be likely from consumption of each fish species and of blue crab (Tables 6a, 6b, and 6c). In gaftopsail catfish, the HQ for PCBs was greater than 2 (Table 6a) and the suggested number of meals less than one per week (0.4). In spotted seatrout, the HQ was 0.86 (Table 6a). The HQs for

PCBs in other species individually were less than 1.0 with the suggested numbers of meals per week commensurately greater than 1 per week. However, the HQ for PCBs in all fish species combined was 1.38, and the suggested number of meals again less than 1 per week (0.7). Adding blue crab to fish reduced the overall HQ for PCBs in samples from Lower Galveston Bay to 0.8. By adding blue crab in equal proportions, those people wishing to eat a mixed species meal could consume one 8-ounce meal per week of such a mixture. The data in Table 6a thus clearly apportion the major proportion of risk of noncancerous adverse health effects from consumption of PCBs in fish from Lower Galveston Bay to consumption of gaftopsail catfish

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 Lower Galveston Bay that healthy adults could consume without significant risk of adverse systemic effects (Table 6a). The SALG estimated these groups could consume 0.4 (8-ounce) meals per week of gaftopsail catfish or 1 (8-ounce) meal per week of spotted seatrout containing PCBs. PCB concentrations in other fish species and in blue crab species were 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 that people limit their consumption of catfish and spotted seatrout from Lower Galveston Bay (Table 6a) and that consuming a diet of mixed species could somewhat alleviate the attendant risk of consuming gaftopsail catfish from Lower Galveston Bay.

PCDFs/Ds

The laboratory analyzed 14 fish and 2 blue crab samples from seven of ten sites for PCDFs/Ds. 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/Ds and the TEQs of PCDFs/Ds in each species at each site. Twelve samples (11 fish and 1 blue crab) contained PCDFs/Ds. Table 5a gives TEQs for each species at each site. Since it is only minimally useful – due to the mobility of the fish – to analyze the effect collection site on PCDF/D concentration, SALG risk assessors ultimately combined collection sites and looked only at species for PCDF/D effects (Table 5b). Table 5b shows the TEQs of PCDFs/Ds in each species independent of collection site, in all fish species combined, in blue crab, and in all fish species combined with blue crab. Gaftopsail catfish contained the highest PCDF/D TEQs, with most of this effect appearing to arise from a single fish that contained 3.4839 mg/kg of PCDFs/Ds. The mean concentration of PCDFs/Ds in gaftopsail catfish exceeded the HAC_{nonca} for 2,3,7,8-TCDD (2.33 pg/g). PCDFs/Ds in other species did not exceed the PCDF/D HAC_{nonca}. SALG risk assessors generated HQs and suggested meals/week for each species containing PCDFs/Ds for all fish species, combined, and for fish and blue crab combined (Table 6a). HQs for PCDFs/Ds did not exceed 1.0 for any named scenario (Table 6a).

Although "collection site" was not an official variable in these comparisons, the SALG risk assessors found it interesting to visually inspect site-specific data to see if differences in toxicant concentrations within or between species occurred at different sites. Assessors observed that gaftopsail catfish collected from Site 2 (Bolivar Spoil Island, Site 3 (Campbell Bayou), Site 4 (Snake Island), and Site 6 (Redfish Island) contained PCBs at higher concentrations than did those from other sites. For the most part, spotted seatrout followed the same pattern (Tables 4a-

4c; 6a-6d),. Gaftopsail catfish and spotted seatrout from Site 6 (Redfish Island) contained PCDFs/Ds at levels approximately 1.5X the $\mathrm{HAC}_{\mathrm{nonca}}$ (Tables 5a and, 6b). The HI for PCBs combined with PCDFs/Ds in gaftopsail catfish collected from Site 6 (Redfish Island) was the highest of any site, at 3.92 (implied meals/week of gaftopsail catfish from Redfish Island were 0.2/week). Eliminating collection site as a factor, gaftopsail catfish and spotted seatrout still had increased hazard quotients and hazard indices, and the subsequent increase in the possibility of higher likelihood of systemic effects (Table 6d). The SALG risk assessors therefore concluded that those recreational fishers who – rather than concentrating fishing activities on areas near Sites 2, 3, 4, and 6, – catch gaftopsail catfish and spotted seatrout from Sites 1, 7, 8, 9, and 10 in Lower Galveston Bay probably have a lower likelihood of systemic adverse health effects from consuming gaftopsail catfish and spotted seatrout containing PCBs and PCDFs/Ds.

Characterization of Theoretical Lifetime Excess Cancer Risk from Consumption of Fish and Blue Crab from Lower Galveston Bay

Calculated lifetime excess cancer risk from consumption of any species of fish or blue crab from Lower Galveston Bay showed that consumption of fish or blue crab containing PCBs alone did not increase the calculated theoretical excess cancer risk (Tables 7a-7c). Calculations also revealed that consuming any fish species or blue crab from Lower Galveston Bay did not increase the calculated theoretical lifetime excess risk of cancer (Table 7d) to a level exceeding the DSHS' acceptable risk level (<1 excess cancer in 10,000 equivalently exposed persons). Particularly, consuming <2.5 meals per week of gaftopsail catfish or <6 meals per week of spotted seatrout from this water body containing PCBs did not increase the calculated theoretical lifetime excess risk of cancer. Nor did blue crab contain PCBs in excess of the $\mathrm{HAC}_{\mathrm{ca}}$ (0.272 mg/kg; Tables 4a-4c; 7a-7c), meaning that blue crab consumption would not be expected to increase the theoretical excess risk of cancer from consuming this species from Lower Galveston Bay (Table 7a).

Blue crab, gaftopsail catfish, red drum, southern flounder, and spotted seatrout (all species except black drum) from Lower Galveston Bay registered the presence of PCDFs/Ds at some concentration. Black drum, blue crab, red drum, and southern flounder contained only low levels of PCDFs/Ds, meaning consumption of these fish would not be limited by the presence of PCDFs/Ds. Conversely, excess cancer risk for consumption of gaftopsail catfish and spotted seatrout, was slightly greater than for consumption of those same species containing only PCBs; such fish had suggested consumption limits of 1.2 meal/week or 2.2 meals per week when PCDF/D risk was calculated. Neither PCBs nor PCDFs/Ds limited consumption of any fish or glue crab to less than one meal per week.

From these data, one understands that carcinogenic risk did not "drive" this risk characterization. Rather, noncarcinogenic effects of these compounds were the driving factor for the recommendations that people should consider limiting consumption of catfish and spotted seatrout from Lower Galveston Bay.

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

Cumulative Systemic Effects

Cumulative adverse health effects may be of concern if people are exposed simultaneously to more than one contaminant in one medium (e.g., fish and/or blue crabs) or in multiple media (multiple media are not discussed in this report because the SALG has no way of knowing the toxicants to which people may be exposed through other media).

In the present risk characterization, risk assessors observed various combinations of metals, pesticides, VOCs, SVOCs, PCBs, and PCDFs/Ds in samples collected from Lower Galveston Bay. Exposure to combinations of some of the observed contaminants could potentially increase damage one or more organ systems [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 concentrations of and the HQs for pesticides, VOCs, and SVOCs many of which may affect the same target organ (for instance, the liver) or have the same mode or mechanism of action were generally far smaller than 1.0, making consumption of fish or blue crab from lower Galveston Bay containing these toxicants unlikely to cause, or result in, cumulative systemic toxicity.[58]

On the other hand, cumulative systemic toxicity from consuming some species of fish from Lower Galveston Bay containing both PCBs and PCDFs/Ds (Tables 6a-6d) could be further increased when PCDFs/Ds were added to PCBs. Table 6a clearly indicates from the calculated likelihood of adverse systemic effects that the greater portion of potential systemic toxicity from consuming fish or blue crab from Lower Galveston Bay should be assigned to the PCBs in gaftopsail catfish and, to a lesser extent, to concentrations of PCBs in spotted seatrout. Nevertheless, risk assessors identified some potential cumulative effects of consuming Lower Galveston Bay catfish and/or spotted seatrout containing both PCBs and PCDFs/Ds. Different levels of risk result from varying concentrations of these contaminants in the fish. For instance, the HQ for PCBs in gaftopsail catfish is almost twice the acceptable HQ of 1.0, resulting in a suggested consumption limit for adults of 0.4 (8 ounce) meals per week (less than two meals per month);the HQ for PCDFs/Ds in gaftopsail catfish was less than 1 with a suggested consumption of 1.5 meals per week. Adding the HQ for total PCDFs/Ds (in TEQs) to that of PCBs yielded an HI in gaftopsail catfish of approximately 3 times that considered of no consequence (<1.0), with suggested meals/week for adults of 0.3 meals/week, down from 0.4 meals/week of gaftopsail catfish (Table 6a). Although the average PCDF/D concentration in spotted seatrout did not exceed the $\text{HAC}_{\text{nonca}}$ and the HQ was less than 1.0, adding PCDFs/Ds in spotted seatrout to PCBs yielded an HI of 1.28 and decreased the suggested consumption of spotted seatrout from an acceptable 1.1 meals/week (PCB-driven) to an unacceptable 0.7 meals/week (Table 6a). Hazard quotients for PCBs in blue crab, black drum, red drum, and southern flounder were less than 1.0. Although adding the HQ for PCDFs/Ds to that of PCBs in these species increased the HI, this measure of cumulative toxicity still did not exceed 1.0. The suggested consumption rate for these species was greater than 1 meal per week.

Although use of hazard index methods to determine cumulative effects of toxicants is common, caution is advised if the toxic endpoint is not the same and/or does not utilize the critical effect of each toxicant because the method is likely to cumulative noncarcinogenic effects estimated by hazard quotient/hazard index methodology may overestimate the cumulative toxicity of the combined toxicants,(this statement is probably true for any mixture of toxicants).[58] The critical organs or effects of PCBs and of PCDFs/Ds are different. However, research suggests that both toxicants are developmental toxicants, affecting in utero development and function of the reproductive organs.[59] Thus, if one knew the RfDs for the developmental effects, the RfD for those effects would be the appropriate toxic effect for calculating cumulative risk. These data are unavailable, so the SALG utilized the HQs from the RfD for critical effects for each toxicant to estimate the cumulative toxicity of consuming low-level concentrations of PCBs and PCDFs/Ds in fish or blue crab from Lower Galveston Bay. Thus, the effects implied by adding the doses of each toxicant (Table 6a) are likely to overestimate effect size, but to an unknown degree.

Cumulative Carcinogenicity

The theoretical excess cancer risk was not increased by consuming any single chemical in fish or shellfish from Lower Galveston Bay. In most assessments of cancer risk from environmental exposures to chemical mixtures, researchers consider any increase in neoplastic activity, whether cancerous or benign or in one or more organs, to be cumulative, no matter the mode or mechanism of action of the contaminant. In this assessment, risk assessors added the calculated carcinogenic risks of PCDFs/Ds to that of PCBs (Table 7a). In each instance, addition of the calculated theoretical lifetime risk of cancer for these chemicals increased the theoretical lifetime excess cancer risk. Nonetheless, the increases were small and did not cause the calculated theoretical lifetime excess cancer risk to exceed 1 excess cancer in 10,000 persons, the cutoff point used by the DSHS to determine whether regulatory action or consumption advice is warranted (Table 7).

Although ingestion of inorganic arsenic did not increase the calculated theoretical lifetime excess risk of cancer, adding this carcinogen to the calculated lifetime excess cancer risk from consuming combined PCBs and PCDFs/Ds in gaftopsail catfish did slightly increase the calculated risk to more than 1 excess cancer in 10,000 equivalently exposed persons. However, the slope factor used to calculate the risk from consuming fish or blue crab from Lower Galveston Bay is based on cancers in those whose drinking water is contaminated with inorganic arsenic.[60] Further, inorganic arsenic has a much higher tolerable daily intake (TDI) from foods (140-150 mcg/day) than might be expected from the CSF calculated for exposure via ingestion of contaminated drinking water. For these reasons, the DSHS did not include arsenic in its calculations of lifetime excess cancer risk from consuming fish and/or blue crab from Lower Galveston Bay.

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 Lower Galveston Bay. Risk assessors from the SALG conclude from the present characterization of potential adverse health effects from consuming contaminated fish from Lower Galveston Bay

1. That the gaftopsail catfish (7 samples) from Lower Galveston Bay analyzed for PCBs all contained these toxicants. The average PCB concentration in gaftopsail catfish exceeded the DSHS HAC_{nonca} (Table 4c) by a factor of approximately 2. The HQ was, consequently, greater than 1.0 (Table 6a). Based on the small sample of gaftopsail catfish examined for PCBs, consumption of gaftopsail catfish from Lower Galveston Bay increased the estimated likelihood of systemic (noncancerous) adverse health effects. The DSHS thereby concludes from this small sample that unlimited consumption of gaftopsail catfish from Lower Galveston Bay containing PCBs **poses an apparent hazard to human health**.

2. That all four gaftopsail catfish from Lower Galveston Bay tested contained PCDFs/Ds. The average concentration in the fish did not exceed the DSHS' HAC_{nonca} for PCDFs/Ds (2.33 ng/kg or 0.00000233 mg/kg). Thus, the HQ for the average concentration was less than 1.0. However, the measured concentrations in the four samples were highly variable, as shown by the standard deviation of ±1.551. Because of the variability in the four measurements, confidence in the reliability of the conclusions made from these concentrations is "low." Therefore, although the DSHS concludes that consumption of gaftopsail catfish from Lower Galveston Bay that contain only PCDFs/Ds (unlikely scenario – see conclusion 3 below) would not likely increase the chances of adverse systemic health effects and thus **pose no apparent hazard to human health**, the DSHS also suggests this conclusion be viewed with caution.

3. That, most importantly, gaftopsail catfish tested for PCBs and PCDFs/Ds from Lower Galveston Bay contain both PCBs and PCDFs/Ds (Tables 4c and 5b) and that, at 2.67, the HI for these two classes of toxicants in gaftopsail catfish is almost 3X the acceptable HI (acceptably HI is <1.0). The likelihood of cumulative (additive) systemic (noncarcinogenic) adverse effects of combined PCBs and PCDFs/Ds is greater than the effect for PCBs or PCDFs/Ds in isolation (Table 6b – see "Discussion for limitations on this conclusion) in those who consume gaftopsail catfish from Lower Galveston Bay (Table 6c). Therefore, the DSHS concludes that unlimited consumption of gaftopsail catfish from Lower Galveston Bay **poses an apparent hazard to human health**. Once again, the small number of samples analyzed for PCBs (7) and PCDFs/Ds (4) decreases confidence in this conclusion.

4. That the calculated lifetime excess cancer risk from consumption of gaftopsail catfish (or any other species taken in 2006-2007 from Lower Galveston Bay) containing either PCBs or PCDFs/Ds was not elevated (Table 7c). Although adding the calculated lifetime excess cancer risk from consuming PCDFs/Ds in gaftopsail catfish to that expected from consuming gaftopsail catfish containing PCBs did increase the risk of cancer, that

elevation in risk from combined contaminants was well below 1 excess cancer in 10,000 equivalently exposed persons (Table 7a). Thus, consumption of gaftop sail catfish is unlikely to pose a significant risk of cancer from PCBs and PCDFs/Ds. Consumption of fish from Lower Galveston Bay **poses no apparent hazard to human health from cancer.**

5. That the average concentration of PCBs in the 47 spotted seatrout collected from across all sites in Lower Galveston Bay did not exceed the HAC_{nonca} for PCBs (0.047 Table 4c) and, therefore, the HQ for PCBs in spotted seatrout was slightly less than 1.0 (Table 4c). Based on the PCB results (Tables 4c and 6a) consumption of spotted seatrout containing only PCBs is unlikely increase the possibility of systemic adverse health effects and would **pose no apparent hazard to human health**.

6. That seven spotted seatrout analyzed for PCDFs/Ds all contained PCDFs/Ds, but the average concentration did not exceed the DSHS HAC_{nonca} value for PCDFs/Ds (Table 5b). Based on an HQ of 0.42, consumption of spotted seatrout containing only PCDFs/Ds is unlikely to result in systemic adverse health effects from eating spotted seatrout (Table 6a) from Lower Galveston Bay. The DSHS concludes – with caution because only 7 spotted seatrout were analyzed for PCDFs/Ds – that consumption of spotted seatrout containing only PCDFs/Ds from Lower Galveston Bay **poses no apparent hazard to human health.**

7. That most importantly, the 7 spotted seatrout contain both PCBs and PCDFs/Ds. While neither PCBs nor PCDFs/Ds alone increased the likelihood of systemic adverse health effects from consuming spotted seatrout, combining the two toxicants without regard to collection site (Table 6d) resulted in an HI of 1.27 (>1.0). Therefore, the DSHS concludes that consumption of spotted seatrout from Lower Galveston Bay containing *both* PCBs and PCDFS/Ds (a likely scenario) **poses an apparent hazard to human health.**

8. That black drum, red drum, southern flounder, and blue crab collected from Lower Galveston Bay during 2006 and 2007did not contain concentrations of PCBs or PCDFs (or other contaminants) that would have resulted in an HQ for any contaminant that exceeded 1.0; nor did any combination of contaminants in these species increase the HI to a value greater than 1.0. Thus, the calculated chances of adverse systemic or cancerous effects – either from one contaminant or from multiple contaminants are not greater in those who would consume black drum, red drum, southern flounder, or blue crab from Lower Galveston Bay than in those who do not consume these species. Based on these results from samples collected in 2006-2007 from Lower Galveston Bay, the DSHS concludes that consumption of a reasonable number of meals/week of black drum, red drum, southern flounder, and/or blue crab species from Lower Galveston Bay **poses no apparent hazard to human health.**

9. That the slight elevations in the HI for "all fish" and "all species" shown in Table 6a is likely an artifact of the presence of PCBs and, possibly, PCDFs/Ds, in gaftopsail catfish and spotted seatrout. As stated in conclusion #8, no red drum, black drum, southern flounder, or blue crab contained these contaminants at concentrations in excess of the HAC_{nonca} for any of those species. Thus, the DSHS – considering this finding a methodological aberration – concludes that consumption of these 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, 61] 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).[62] Declarations of prohibited harvesting areas are enforceable under the Texas Health and Safety Code, Subchapter D, parts 436.091 and 436.101.[62] 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, to a lesser extent, spotted seatrout, from Lower Galveston Bay **poses an apparent hazard to public health**. Therefore, the SALG recommends

1. That the DSHS advises all who eat catfish and spotted seatrout from Lower Galveston Bay that these species contain PCBs and PCDFs/Ds at concentrations that, when combined, may increase the risk of adverse systemic health effects in those who regularly consume them. For example, it might be wise to advise normally healthy, 70+ kg – adults to consume no more than 2.0 meals per month consisting of a mix of catfish and spotted seatrout. Those who consume only catfish could be advised to eat no more than 1 meal per month of these species, while those who consume only spotted seatrout could eat approximately 3 meals per month.

2. That the DSHS advises that young children and women who are breast-feeding avoid consuming catfish and spotted seatrout from Lower Galveston Bay (some research shows that 12-14% of the total body burden of PCBs and/or PCDFs/Ds at age 25 years is attained by age six months in those breast-fed by mothers with high body burdens of these toxicants).[63] Women who are pregnant or who may become pregnant (in utero exposure to PCBs in combination with PCDFs/Ds can damage the developing reproductive system) should avoid consuming catfish and spotted seatrout from Lower Galveston Bay. Others who belong to groups with greater susceptibility to the adverse

effects of long-term exposure to PCBs and/or PCDFs/Ds (i.e., the elderly, the chronically ill, recipients of transplanted organs, others with suppressed immune systems) should be advised to consider eating no catfish or spotted seatrout from Lower Galveston Bay.

3. That the DSHS advises people they are free to consume black drum, red drum, southern flounder, or blue crab from Lower Galveston Bay.

4. That the DSHS continues to monitor fish and shellfish from Lower Galveston Bay for changes in contaminants or in contaminant concentrations that would necessitate a change in consumption advice for fish or shellfish from these waters .

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.[64] 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.[65]

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. Lower Galveston Bay Sample Site Map

TABLES

Table 1 Fish and blue crab collected from Lower Galveston Bay between November 2006 and May 2007. Sample number, species, length, and weight were recorded for each sample collected.

Sample Number	Species	Length (mm)	Weight (g)
Site 1 Hanna Reef			
GAL219	Red drum	943	8263
GAL220	Red drum	580	2523
GAL221	Black drum	530	2072
GAL222	Black drum	574	2596
GAL223	Blue crab	165	
GAL224	Blue crab	152	
Site 2 Bolivar Spoil Island			
GAL194	Spotted seatrout	450	870
GAL195	Spotted seatrout	449	874
GAL196	Spotted seatrout	377	482
GAL197	Spotted seatrout	562	1875
GAL198	Spotted seatrout	670	2869
GAL199	Spotted seatrout	665	3050
GAL200	Spotted seatrout	515	1201
GAL201	Spotted seatrout	440	875
GAL202	Spotted seatrout	447	832
GAL203	Spotted seatrout	453	1033
GAL205	Red drum	590	1979
GAL206	Southern flounder	532	2203
GAL208	Gaftopsail catfish	597	2139
GAL211	Black drum	630	3573
GAL213	Blue crab	163	
GAL214	Blue crab	167	
GAL215	Blue crab	169	
Site 3 Campbell Bayou			
GAL159	Black drum	571	2930
GAL160	Southern flounder	510	1949
GAL162	Gaftopsail catfish	635	2513
GAL163	Gaftopsail catfish	621	2492
GAL165	Red drum	630	2403
GAL167	Spotted seatrout	570	2030
GAL168	Spotted seatrout	433	894
GAL169	Spotted seatrout	330	373
GAL250	Spotted seatrout	355	417
GAL251	Spotted seatrout	372	476
GAL252	Spotted Seatrout	351	411

Sample Number	Species	Length (mm)	Weight (g)
GAL253	Spotted seatrout	339	360
GAL254	Spotted seatrout	359	446
GAL255	Spotted seatrout	342	369
GAL256	Spotted seatrout	380	530
GAL257	Spotted seatrout	420	664
GAL259	Spotted seatrout	405	646
GAL260	Spotted seatrout	394	554
GAL170	Blue crab	171	
Site 4 Snake Island			
GAL150	Southern flounder	440	1094
GAL151	Southern flounder	540	2133
GAL152	Gaftopsail catfish	615	2021
GAL153	Gaftopsail catfish	487	1123
GAL154	Gaftopsail catfish	452	869
GAL155	Spotted seatrout	500	1190
GAL156	Blue crab	174	
GAL157	Blue crab	173	
Site 5 Dollar Point			
GAL180	Red drum	611	2175
GAL181	Spotted seatrout	523	1374
GAL182	Spotted seatrout	539	1557
GAL183	Spotted seatrout	482	1163
GAL184	Spotted seatrout	419	747
GAL185	Spotted seatrout	475	1141
GAL186	Spotted seatrout	390	590
GAL187	Spotted seatrout	429	813
GAL188	Southern flounder	592	2905
GAL191	Black drum	567	2614
GAL192	Blue crab	179	
GAL193	Blue crab	154	
Site 6 Redfish Island			
GAL171	Spotted seatrout	662	2801
GAL172	Spotted seatrout	429	722
GAL173	Spotted seatrout	458	838
GAL174	Gaftopsail catfish	620	2387
GAL175	Red drum	575	1857
GAL177	Black drum	877	10442
GAL178	Southern flounder	512	1816

Sample Number	Species	Length (mm)	Weight (g)
Site 7 Galveston Jetties			
GAL266	Spotted seatrout	460	1043
GAL267	Spotted seatrout	431	726
Site 8 Pelican Island Bridge			
GAL270	Spotted seatrout	404	635
GAL271	Spotted seatrout	433	771
Site 9 Offat's Bayou			
GAL261	Spotted seatrout	480	1225
GAL262	Spotted seatrout	384	590
GAL263	Spotted seatrout	409	680
GAL264	Spotted seatrout	382	590
GAL265	Spotted seatrout	412	635
GAL272	Spotted seatrout	431	590
GAL273	Spotted seatrout	433	726
GAL274	Spotted seatrout	418	544
Site 10 Moses Lake			
GAL258	Spotted seatrout	380	558

Table 2a. Arsenic (mg/kg) in fish and/or blue crab collected in 2006 and 2007 from Lower Galveston Bay.

Species	# Detected/ # Sampled	Total Arsenic Mean Concentration ± S.D. (Min-Max)	Inorganic Arsenic Mean Concentration[e]	Health Assessment Comparison Value (mg/kg) [f]	Basis for Comparison Value
Black drum	6/6	2.049 ±1.200 (0.731-**3.686**[g])	0.205	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
Blue crab	10/10	1.838 ±0.803 (0.805-3.549)	0.184		
Gaftopsail catfish	7/7	0.927 ±0.542 (0.296-1.826)	0.093		
Red drum	6/6	0.828 ±0.395 (0.252-1.433)	0.083		
Southern flounder	6/6	0.575 ±0.164 (0.364-0.830)	0.058		
Spotted seatrout	47/47	0.331 ±0.100 (0.110-0.607)	0.033		
All species	82/82	0.745 ±0.760 (0.110-**3.686**)	0.075		

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[e] *Most arsenic in fish and shellfish occurs as organic arsenic, considered virtually nontoxic to humans. For calculation of risk parameters, the SALG assumes total arsenic in fish or shellfish to be 10% inorganic arsenic*

[f] *For noncarcinogenic effects, derived from the MRL(ATSDR) or RfD (USEPA); for carcinogenic effects, derived from the USEPA slope factor. Assumptions: body weight of 70 kg, consumption rate of 30 grams per day, and, for carcinogens, a 30-year exposure period and an acceptable risk level (ARL) of* $1x10^{-4}$ *(one excess cancer in 10,000 equivalently exposed persons).*

[g] *Emboldened text denotes concentrations that exceed one or more HAC values for an element or compound.*

Table 2b. Other inorganic contaminants (mg/kg) in fish and/or blue crab collected in 2006 and 2007 from Lower 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
Blue crab	6/10	0.018 ±0.019 (ND-0.070)		
Gaftopsail catfish	0/7	ND		
Red drum	1/6	BDL		
Southern flounder	0/6	ND		
Spotted seatrout	2/47	BDL[i]		
All species	9/82	0.012 ±0.006 (ND-0.070)		
Copper				
Black drum	6/6	0.331 ±0.102 (0.202-0.492)	333	National Academy of Science Upper Limit: 0.143 mg/kg–day
Blue crab	10/10	9.244 ±3.063 (4.639-13.163)		
Gaftopsail catfish	7/7	0.389 ±0.131 (0.185-0.500)		
Red drum	6/6	1.524 ±2.116 (0.193-5.382)		
Southern flounder	6/6	0.157 ±0.069 (0.096-0.280)		
Spotted seatrout	47/47	0.249 ±0.161 (0.141-1.232)		
All species	82/82	1.451 ±3.160 (0.096-13.163)		

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[h] *ND: “Not Detected:" – Contaminants were reported as "ND" when the contaminant concentration could not be distinguished from "0" or from the laboratory's Method Detection Limit (MDL).*

[i] *BDL: “Below Detection Limit” – Contaminants detected at a concentration below the laboratory’s method detection limit but that could be estimated from the standard curve. The laboratory utilizes a “J” qualification to denote the discernable presence of a contaminant at concentrations **estimated** as different from the sample blank. A “<” followed by the laboratory’s MDL for the contaminant denotes a contaminant detected as present at a concentration below the detection limit, but not estimable.*

Table 2c. Other inorganic Contaminants (mg/kg) in fish and/or blue crab collected in 2006 and 2007 from Lower Galveston Bay.

Species	# Detected/ # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (mg/kg)	Basis for Comparison Value
Lead				
Black drum	6/6	BDL	0.6	EPA IEUBKwin
Blue crab	10/10	0.067 ±0.068 (BDL-0.254)		
Gaftopsail catfish	7/7	BDL		
Red drum	6/6	0.068 ±0.072 (BDL-0.216)		
Southern flounder	6/6	BDL		
Spotted seatrout	47/47	0.051 ±0.025 (BDL-0.175)		
All species	82/82	0.052 ±0.036 (BDL-0.254)		
Mercury				
Black drum	6/6	0.091 ±0.054 (0.045-0.196)	0.7	ATSDR chronic oral MRL: 0.0003 mg/kg–day
Blue crab	10/10	0.071 ±0.024 (0.040-0.126)		
Gaftopsail catfish	7/7	0.267 ±0.073 (0.167-0.396)		
Red drum	6/6	0.162 ±0.197 (0.047-0.556)		
Southern flounder	6/6	0.057 ±0.022 (0.030-0.082)		
Spotted seatrout	47/47	0.081 ±0.049 (0.038-0.282)		
All Species	82/82	0.101 ±0.087 (0.030-0.556)		
Selenium				
Black drum	6/6	1.019 ±0.220 (0.742-1.330)	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.
Blue crab	10/10	0.705 ±0.254 (0.459-1.121)		
Gaftopsail catfish	7/7	0.218 ±0.049 (0.150-0.304)		
Red drum	6/6	0.744 ±0.151 (0.456-0.874)		
Southern flounder	6/6	0.705 ±0.150 (0.440-0.859)		
Spotted seatrout	47/47	0.719 ±0.124 (0.504-0.975)		
All Species	82/82	0.697 ±0.223 (0.150-1.330)		

Table 2d. Other inorganic contaminants (mg/kg) in fish and/or blue crab collected in 2006 and 2007 from Lower 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	2.965 ±0.619 (2.105-3.744)	700	EPA chronic oral RfD: 0.3 mg/kg–day
Blue crab	10/10	31.541 ±3.477 (25.358-35.004)		
Gaftopsail catfish	7/7	5.052 ±1.549 (3.215-7.438)		
Red drum	6/6	7.875 ±12.789 (2.003-33.957)		
Southern flounder	6/6	1.876 ±0.630 (1.191-2.655)		
Spotted seatrout	47/47	2.462 ±0.505 (1.835-4.039)		
All Species	82/82	6.619 ±10.075 (1.191-35.004)		

Table 3. Pesticides (mg/kg) in fish and/or blue crab collected in 2006 and 2007 from Lower Galveston Bay.

Species	# Detected / # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (mg/kg)	Basis for Comparison Value
Total Chlordane				
Black drum	4/6	BDL	1.167 1.6	EPA chronic oral RfD: 0.0005 mg//kg–day EPA slope factor 0.35 per mg/kg–day
Blue crab	5/10	BDL		
Gaftopsail catfish	7/7	0.004±0.003 (BDL-0.009)		
Red drum	5/6	BDL		
Southern flounder	6/6	BDL		
Spotted seatrout	47/47	0.003±0.002 (BDL-0.011)		
All Species	74/82	0.003±0.002 (ND-0.011)		
4,4’ DDE				
Black drum	6/6	0.001±0.0004 (BDL-0.002)	1.167 1.6	EPA chronic oral RfD: 0.0005 mg//kg–day EPA slope factor 0.34 per mg/kg–day
Blue crab	10/10	BDL		
Gaftopsail catfish	7/7	0.018±0.007 (0.008-0.026)		
Red drum	6/6	BDL		
Southern flounder	6/6	0.002±0.001 (BDL-0.005)		
Spotted seatrout	47/47	0.004±0.003 (BDL-0.012)		
All Species	82/82	0.005±0.005 (BDL-0.026)		

Table 4a. PCBs (mg/kg) in fish and/or blue crab collected in 2006 and 2007 from Lower Galveston Bay (presented by species and site).

Species	# Detected / # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (mg/kg)	Basis for Comparison Value
Site 1 Hanna Reef				
Black drum	2/2	0.010± 0.000 (0.010-0.010)	0.047 0.272	EPA chronic oral RfD: 0.00002 mg/kg–day EPA slope factor: 2.0 per mg/kg–day
Blue crab	0/2	ND		
Red drum	2/2	0.010± 0.0003 (0.010-0.0104)		
All Fish, Site 1	4/4	0.011± 0.0002 (0.010-0.0104)		
All Species, Site 1	4/6	0.010± 0.0003 (ND-0.0104)		
Site 2 Bolivar Spoil Island				
Black drum	1/1	0.011	0.047 0.272	EPA chronic oral RfD: 0.00002 mg/kg–day EPA slope factor: 2.0 per mg/kg–day
Blue crab	3/3	0.010± 0.0008 (0.009-0.010)		
Gaftopsail catfish	1/1	**0.077**		
Red drum	1/1	0.010		
Southern flounder	1/1	0.016		
Spotted seatrout	10/10	0.025± 0.020 (0.009-**0.073**)		
All Fish, Site 2	14/14	0.026± 0.023 (0.009-**0.077**)		
All Species, Site 2	17/17	0.023± 0.021 (0.009-**0.077**)		
Site 3 Campbell 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	1/1	0.009		
Gaftopsail catfish	2/2	**0.088**± 0.012 (**0.080-0.096**)		
Red drum	1/1	0.020		
Southern flounder	1/1	0.013		
Spotted seatrout	13/13	**0.052**± 0.033 (0.022-**0.118**)		
All Fish, Site 3	18/18	**0.050**± 0.034 (0.010-**0.118**)		
All Species, Site 3	19/19	**0.048**± 0.035 (0.009-**0.118**)		

Table 4b. PCBs (mg/kg) in fish and/or blue crab collected in 2006 and 2007 from Lower Galveston Bay (presented by species and site).

Species	# Detected / # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (mg/kg)	Basis for Comparison Value
Site 4 Snake Island				
Blue crab	2/2	0.014± 0.004 (0.011-0.017)	0.047 0.272	EPA chronic oral RfD: 0.00002 mg/kg–day EPA slope factor: 2.0 per mg/kg–day
Gaftopsail catfish	3/3	**0.103**± 0.002 (**0.102-0.105**)		
Southern flounder	2/2	0.024± 0.012 (0.016-0.032)		
Spotted seatrout	1/1	0.042		
All Fish, Site 4	6/6	**0.067**± 0.041 (0.016-**0.105**)		
All Species, Site 3	8/8	**0.054**± 0.043 (0.011-**0.105**)		
Site 5 Dollar Point				
Black drum	1/1	0.013	0.047 0.272	EPA chronic oral RfD: 0.00002 mg/kg–day EPA slope factor: 2.0 per mg/kg–day
Blue crab	1/1	0.011		
Red drum	1/1	0.017		
Southern flounder	2/2	0.033± 0.020 (0.019-**0.048**)		
Spotted seatrout	7/7	0.040± 0.013 (0.019-**0.058**)		
All Fish, Site 5	11/11	0.035± 0.015 (0.013-**0.058**)		
All Species, Site 5	12/12	0.033± 0.016 (0.011-**0.058**		
Site 6 Redfish Island				
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	1/1	0.012		
Gaftopsail catfish	1/1	**0.113**		
Red drum	1/1	0.013		
Spotted seatrout	3/3	**0.052**± 0.029 (0.030-**0.085**)		
All Fish, Site 6	6/6	**0.049**± 0.042 (0.010-**0.113**)		
All Species, Site 6	7/7	0.043± 0.040 (0.010-**0.113**)		

Table 4c. PCBs (mg/kg) in fish and/or blue crab collected in 2006 and 2007 from Lower Galveston Bay (presented by species and site).

Species	# Detected / # Sampled	Mean Concentration ± S.D. (Min-Max)	Health Assessment Comparison Value (mg/kg)	Basis for Comparison Value
Site 7 Galveston Jetties				
Spotted seatrout	2/2	0.019± 0.0003 (0.0189-0.0194)	0.047 0.272	EPA chronic oral RfD: 0.00002 mg/kg–day EPA slope factor: 2.0 per mg/kg–day
Site 8 Pelican Island				
Spotted seatrout	2/2	0.027± 0.003 (0.025-0.029)	0.047 0.272	EPA chronic oral RfD: 0.00002 mg/kg–day EPA slope factor: 2.0 per mg/kg–day
Site 9 Offat's Bayou				
Spotted seatrout	8/8	0.042± 0.047 (0.012-**0.155**)	0.047 0.272	EPA chronic oral RfD: 0.00002 mg/kg–day EPA slope factor: 2.0 per mg /kg–day
Site 10 Moses Lake				
Spotted seatrout	1/1	0.043	0.047 0.272	EPA chronic oral RfD: 0.00002 mg/kg–day EPA slope factor: 2.0 per mg/kg–day
All Sites				
Black drum	6/6	0.011± 0.001 (0.0096-0.013)	0.047 0.272	EPA chronic oral RfD: 0.00002 mg/kg–day EPA slope factor: 2.0 per mg/kg–day
Blue crab	8/10	0.011± 0.002 (ND-0.017)		
Gaftopsail catfish	7/7	**0.097**± 0.014 (**0.077-0.113**)		
Red drum	6/6	0.013± 0.004 (0.010-0.020)		
Southern flounder	6/6	0.024± 0.014 (0.013-**0.048**)		
Spotted seatrout	47/47	0.040± 0.030 (0.009-**0.155**)		
All Fish	72/72	0.039± 0.033 (0.009-**0.155**)		
All Species	80/82	0.036± 0.032 (ND-**0.155**)		

Table 5a. PCDFs/PCDDs toxicity equivalents (TEQs – shown in pg/g) in fish and/or blue crab collected in 2006 and 2007 from Lower 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 Hanna Reef				
Black drum	0/1	ND	2.33 3.49	ATSDR chronic oral MRL: 1.0 x 10^{-9} mg/kg/day EPA slope factor: 1.56 x 10^{5} per mg/kg/day
Red drum	1/1	0.0119		
All Fish, Site 1	1/2	0.0060± 0.0084 (ND-0.0119)		
Site 2 Bolivar Spoil Island				
Blue crab	0/1	ND	2.33 3.49	ATSDR chronic oral MRL: 1.0 x 10^{-9} mg/kg/day EPA slope factor: 1.56 x 10^{5} per mg/kg/day
Gaftopsail catfish	1/1	1.6740		
Spotted seatrout	1/1	0.0201		
All Fish, Site 2	2/2	0.8471± 1.1694 (0.0201-1.6740)		
All Species, Site 2	2/3	0.5647± 0.9607 (ND-1.6740)		
Site 3 Campbell Bayou				
Gaftopsail catfish	1/1	0.1652	2.33 3.49	ATSDR chronic oral MRL: 1.0 x 10^{-9} mg/kg/day EPA slope factor: 1.56 x 10^{5} per mg/kg/day
Spotted seatrout	1/1	0.0897		
All Fish, Site 3	2/2	0.1275±0.0534 (0.0897-0.1652)		
Site 4 Snake Island				
Blue crab	1/1	0.1321	2.33 3.49	ATSDR chronic oral MRL: 1.0 x 10^{-9} mg/kg/day EPA slope factor: 1.56 x 10^{5} per mg/kg/day
Gaftopsail catfish	1/1	0.2711		
All Species, Site 2	2/2	0.2016±0.0983 (0.1321-0.2711)		
Site 5 Dollar Point				
Red drum	0/1	ND	2.33 3.49	ATSDR chronic oral MRL: 1.0 x 10^{-9} mg/kg/day EPA slope factor: 1.56 x 10^{5} per mg/kg/day
Southern flounder	1/1	0.0011		
Spotted seatrout	1/1	1.4858		
All Fish, Site 5	2/3	0.4956 ± 0.8575 (ND-1.4858)		
Site 6 Redfish Island				
Black drum	0/1	ND	2.33 3.49	ATSDR chronic oral MRL: 1.0 x 10^{-9} mg/kg/day EPA slope factor: 1.56 x 10^{5} per mg/kg/day
Gaftopsail catfish	1/1	**3.4839**		
Spotted seatrout	1/1	**3.3090**		
All Fish, Site 6	2/3	2.2643 ± 1.9629 (ND-**3.4839**)		

Table 5b. PCDF/PCDD toxicity equivalents (TEQs – shown in pg/g) in fish and/or blue crab collected in 2006 and 2007 from Lower 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 7 Galveston Jetties				
Spotted seatrout	1/1	0.0007	2.33 3.49	ATSDR chronic oral MRL: 1.0 x 10^{-9} mg/kg/day EPA slope factor: 1.56 x 10^{5} per mg/kg/day
All Sites				
Black drum	0/2	ND	2.33 3.49	ATSDR chronic oral MRL: 1.0 x 10^{-9} mg/kg/day EPA slope factor: 1.56 x 10^{5} per mg/kg/day
Blue crab	1/2	0.06605± 0.0934 (ND-0.1321)		
Gaftopsail catfish	4/4	1.3986± 1.5510 (0.1652-**3.4839**)		
Red drum	1/2	0.005950± 0.0084 (ND-0.0119)		
Southern flounder	1/1	0.0011		
Spotted seatrout	5/5	0.9811± 1.4451 (0.0007-**3.3090)**		
All Fish	11/14	0.7509± 1.2500 (ND-**3.4839**)		
All Species	12/16	0.6653± 1.1872 (ND-**3.4839**)		

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 and 2007 from Lower Galveston Bay. Table 6a also provides suggested weekly eight-ounce meal consumption rates for 70-kg adults.[j]

Species/Contaminant	Hazard Quotient	Meals per Week
Black Drum		
PCBs	0.23	4.1
PCDDs/PCDFs	0.00	Unlimited
Hazard Index (meals per week)	0.23 (4.1)	
Blue Crab		
PCBs	0.23	4.0
PCDDs/PCDFs	0.03	32.7
Hazard Index (meals per week)	0.26 (3.6)	
Gaftopsail Catfish		
PCBs	**2.07**[k]	**0.4**
PCDDs/PCDFs	0.60	1.5
Hazard Index (meals per week)	**2.67 (0.3)**	
Red Drum		
PCBs	0.29	3.2
PCDDs/PCDFs	0.002	362.8
Hazard Index (meals per week)	0.29 (3.2)	
Southern Flounder		
PCBs	0.51	1.8
PCDDs/PCDFs	0.0004	1962.5
Hazard Index (meals per week)	0.51 (1.8)	
Spotted Seatrout		
PCBs	0.86	1.1
PCDDs/PCDFs	0.42	2.2
Hazard Index (meals per week)	**1.28 (0.7)**	
All Fish		
PCBs	0.85	1.1
PCDDs/PCDFs	0.54	1.7
Hazard Index (meals per week)	**1.38 (0.7)**	
All Species		
PCBs	0.77	1.2
PCDDs/PCDFs	0.29	3.2
Hazard Index (meals per week)	**1.06 (0.9)**	

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[j] *DSHS assumes that children under the age of 12 years and/or those who weigh less than 35 kg eat 4-ounce meals.*

[k] *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 and 2007 from Lower Galveston Bay (presented by species, site, and contaminant). Table 6b also provides suggested weekly eight-ounce meal consumption rates for 70-kg adults. [j]

Species/ Site/ Contaminant	Hazard Quotient (Meals per Week)					
	Hanna Reef	**Bolivar Spoil Island**	**Campbell Bayou**	**Snake Island**	**Dollar Point**	**Redfish Island**
Black Drum						
PCBs	0.21 (4.3)	0.23 (4.0)	0.21 (4.5)	Black drum not collected	0.28 (3.3)	0.21 (4.3)
PCDDs/PCDFs	0.00 (unlimited)	No black drum samples analyzed	No black drum samples analyzed		No black drum samples analyzed	0.00 (unlimited)
Hazard Index	0.21 (4.3)					0.21 (4.3)
Hazard Index, All Sites	0.23 (4.1)					
Blue Crab						
PCBs	0.21 (4.5)	0.20 (4.5)	0.20 (4.7)	0.30 (3.1)	0.23 (4.1)	0.25 (3.7)
PCDDs/PCDFs	No blue crab samples analyzed	0.00 (unlimited)	No blue crab samples analyzed	0.06 (16.3)	No blue crab samples analyzed	No blue crab samples analyzed
Hazard Index		0.20 (4.5)		0.36 (2.6)		
Hazard Index, All Sites	0.26 (3.6)					
Gaftopsail Catfish						
PCBs	Gaftopsail catfish not collected	**1.64 (0.6)**	**1.89 (0.5)**	**2.22 (0.4)**	Gaftopsail catfish not collected	**2.43 (0.4)**
PCDDs/PCDFs		0.71 (1.3)	0.07 (13.1)	0.12 (8.0)		**1.49 (0.6)**
Hazard Index		**2.36 (0.4)**	**1.96 (0.5)**	**2.33 (0.4)**		**3.92 (0.2)**
Hazard Index, All Sites	**2.67 (0.3)**					
Red Drum						
PCBs	0.22 (4.2)	0.20 (4.5)	0.43 (2.2)	Red drum not collected	0.36 (2.6)	0.29 (3.2)
PCDDs/PCDFs	0.005 (181.4)	No red drum samples analyzed	No red drum samples analyzed		0.00 (unlimited)	No red drum samples analyzed
Hazard Index	0.22 (4.1)				0.36 (2.6)	
Hazard Index, All Sites	0.29 (3.2)					

Table 6c. Hazard quotients (HQ) and hazard indices (HI) for PCDF/PCDDs and/or PCBs in fish and/or blue crab collected in 2006 and 2007 from Lower Galveston Bay. Table 6c also provides suggested weekly eight-ounce meal consumption rates for 70-kg adults. [j]

Species/ Site/ Contaminant	Hazard Quotient (Meals per Week)					
	Hanna Reef	**Bolivar Spoil Island**	**Campbell Bayou**	**Snake Island**	**Dollar Point**	**Redfish Island**
Southern Flounder						
PCBs	Southern flounder not collected	0.33 (2.8)	0.28 (3.3)	0.51 (1.8)	0.71 (1.3)	Southern flounder not collected
PCDDs/PCDFs		No southern flounder samples analyzed	No southern flounder samples analyzed	No southern flounder samples analyzed	0.0005 (1962.5)	
Hazard Index					0.72 (1.3)	
Hazard Index, All Sites	0.51 (1.8)					
All Fish						
PCBs	0.22 (4.3)	0.55 (1.7)	**1.07 (0.9)**	**1.43 (0.6)**	0.74 (1.2)	**1.04 (0.9)**
PCDDs/PCDFs	0.003 (362.8)	0.36 (2.5)	0.05 (16.9)	0.12 (8.0)	0.21 (4.4)	0.97 (1.0)
Hazard Index	0.22 (4.2)	0.91 (1.0)	**1.13 (0.8)**	**1.55 (0.6)**	0.95 (1.0)	**2.01 (0.5)**
Hazard Index, All Sites	**1.38 (0.7)**					
All Species						
PCBs	0.21 (4.3)	0.49 (1.9)	**1.02 (0.9)**	**1.15 (0.8)**	0.70 (1.3)	0.93 (1.0)
PCDDs/PCDFs	0.003 (362.8)	0.24 (3.8)	0.05 (16.9)	0.086 (10.7)	0.21 (4.4)	0.97 (1.0)
Hazard Index	0.22 (4.3)	0.73 (1.3)	**1.08 (0.9)**	**1.23 (0.8)**	0.91 (1.0)	**1.90 (0.5)**
Hazard Index, All Sites	**1.06 (0.9)**					

Table 6d. Hazard quotients (HQ's) and hazard indices (HI's) for PCDFs/PCDDs and/or PCBs in spotted seatrout collected in 2006 and 2007 from Lower Galveston Bay (presented by site and contaminant). Table 6d also provides suggested weekly eight-ounce meal consumption rates for 70-kg adults. [j]

Contaminant/ Site	**Hazard Quotient (Meals per Week)**									
	Hanna Reef	**Bolivar Spoil Island**	**Campbell Bayou**	**Snake Island**	**Dollar Point**	**Redfish Island**	**Galveston Jetties**	**Pelican Island**	**Offat's Bayou**	**Moses Lake**
PCBs	Spotted seatrout not collected	0.52 (1.7)	**1.12 (0.8)**	0.91 (1.0)	0.87 (1.1)	**1.10 (0.8)**	0.41 (2.3)	0.58 (1.6)	0.90 (1.0)	0.92 (1.0)
PCDDs/PCDFs		0.009 (107.4)	0.04 (24.1)	No spotted seatrout samples analyzed	0.64 (1.5)	**1.32 (0.7)**	0.0003 (3083.9)	No spotted seatrout samples analyzed	No spotted seatrout samples analyzed	No spotted seatrout samples analyzed
Hazard Index		0.54 (1.7)	**1.16 (0.8)**		**1.50 (0.6)**	**2.43 (0.4)**	0.41 (2.3)			
Hazard Index, All Sites	**1.27 (0.7)**									

Table 7a. Theoretical lifetime excess cancer risk from consuming PCDFs/PCDDs, and/or PCBs in fish and blue crab collected in 2006 and 2007 from Lower Galveston Bay. Table 7a also provides suggested weekly eight-ounce meal consumption rates for 70-kg adults. [j]

Species/Contaminant	Theoretical Lifetime Excess Cancer Risk		Meals per Week
	Risk	1 excess cancer per number exposed	
Black Drum			
PCBs	3.9E-06	256,409	23.7
PCDDs/PCDFs	0		unlimited
Cumulative Theoretical Lifetime Excess Cancer Risk (meals/week)	3.9E-06	256,409	23.7
Blue Crab			
PCBs	3.9E-06	254,247	23.5
PCDDs/PCDFs	1.9E-06	528,392	48.8
Cumulative Theoretical Lifetime Excess Cancer Risk (meals/week)	5.8E-06	171,653	15.9
Gaftopsail Catfish			
PCBs	3.6E-05	28,160	2.6
PCDDs/PCDFs	4.0E-05	24,955	2.3
Cumulative Theoretical Lifetime Excess Cancer Risk (meals/week)	7.6E-05	13,230	1.2
Red Drum			
PCBs	4.9E-06	202,697	18.7
PCDDs/PCDFs	1.7E-07	5,865,594	541.9
Cumulative Theoretical Lifetime Excess Cancer Risk (meals/week)	5.1E-06	195,926	18.1
Southern Flounder			
PCBs	8.7E-06	114,580	10.6
PCDDs/PCDFs	3.2E-08	31,727,532	2931.1
Cumulative Theoretical Lifetime Excess Cancer Risk (meals/week)	8.8E-06	114,168	10.5
Spotted Seatrout			
PCBs	1.5E-05	68,040	6.3
PCDDs/PCDFs	2.8E-05	35,574	3.3
Cumulative Theoretical Lifetime Excess Cancer Risk (meals/week)	4.3E-05	23,360	2.2
All Fish			
PCBs	1.5E-05	68,918	6.4
PCDDs/PCDFs	2.2E-05	46,478	4.3
Cumulative Theoretical Lifetime Excess Cancer Risk (meals/week)	3.6E-05	27,758	2.6
All Species			
PCBs	1.3E-05	75,642	7.0
PCDDs/PCDFs	1.9E-05	52,459	4.8
Cumulative Theoretical Lifetime Excess Cancer Risk (meals/week)	3.2E-05	30,976	2.9

Table 7b. Theoretical lifetime excess cancer risk from consuming PCDFs/PCDDs and/or PCBs in fish and blue crab collected in 2006 and 2007 from Lower Galveston Bay. Table 7b also provides suggested weekly eight-ounce meal consumption rates for 70-kg adults.[j]

Species/ Site/ Contaminant	Theoretical Lifetime Excess Cancer Risk (Meals per Week)					
	Hanna Reef	**Bolivar Spoil Island**	**Campbell Bayou**	**Snake Island**	**Dollar Point**	**Redfish Island**
Black Drum						
PCBs	3.7E-06 (25.1)	4.0E-06 (23.2)	3.5E-06 (26.2)	Black drum not collected	4.9E-06 (18.9)	3.7E-06 (25.1)
PCDDs/PCDFs	0.0 (unlimited)	No black drum samples analyzed	No black drum samples analyzed		No black drum samples analyzed	0.0 (unlimited)
Cumulative Excess Cancer Risk	3.7E-06 (25.1)					3.7E-06 (25.1)
Cumulative Excess Cancer Risk, All Sites	3.9E-06 (23.7)					
Blue Crab						
PCBs	3.5E-06 (26.2)	3.5E-06 (26.3)	3.4E-06 (27.3)	5.1E-06 (18.1)	3.9E-06 (23.9)	4.3E-06 (21.7)
PCDDs/PCDFs	No blue crab samples analyzed	0.0 (unlimited)	No blue crab samples analyzed	3.8E-06 (24.4)	No blue crab samples analyzed	No blue crab samples analyzed
Cumulative Excess Cancer Risk		3.5E-06 (26.3)		8.9E-06 (10.4)		
Cumulative Excess Cancer Risk, All Sites	5.8E-06 (15.9)					
Gaftopsail Catfish						
PCBs	Gaftopsail catfish not collected	2.8E-05 (3.3)	3.2E-05 (2.9)	3.8E-05 (2.4)	Gaftopsail catfish not collected	4.2E-05 (2.2)
PCDDs/PCDFs		4.8E-05 (1.9)	4.7E-06 (19.5)	7.8E-06 (11.9)		**1.0E-04 (0.9)**
Cumulative Excess Cancer Risk		7.6E-05 (1.2)	3.7E-05 (2.5)	4.6E-05 (2.0)		**1.4E-04 (0.7)**
Cumulative Excess Cancer Risk, All Sites	7.56E-05 (1.2)					
Red Drum						
PCBs	3.7E-06 (24.7)	3.7E-06 (25.1)	7.3E-06 (12.6)	Red drum not collected	6.2E-06 (14.9)	4.9E-06 (18.9)
PCDDs/PCDFs	3.4E-07 (270.9)	No red drum samples analyzed	No red drum samples analyzed		0.0 (unlimited)	No red drum samples analyzed
Cumulative Excess Cancer Risk	4.1E-06 (22.6)				6.2E-06 (14.9)	
Cumulative Excess Cancer Risk, All Sites	5.1E-06 (18.1)					

Table 7c. Theoretical lifetime excess cancer risk from consuming PCDFs/PCDDs, and/or PCBs in fish and blue crab collected in 2006 and 2007 from Lower Galveston Bay. Table 7c also provides suggested weekly eight-ounce meal consumption rates for 70-kg adults. [j]

Species/ Site/ Contaminant	Theoretical Lifetime Excess Cancer Risk (Meals per Week)					
	Hanna Reef	**Bolivar Spoil Island**	**Campbell Bayou**	**Snake Island**	**Dollar Point**	**Redfish Island**
Southern Flounder						
PCBs	Southern flounder not collected	5.6E-06 (16.6)	4.8E-06 (19.3)	8.8E-06 (10.6)	1.2E-05 (7.5)	Southern flounder not collected
PCDDs/PCDFs		No southern flounder samples analyzed	No southern flounder samples analyzed	No southern flounder samples analyzed	3.2E-08 (2931.1)	
Cumulative Excess Cancer Risk					1.2E-05 (7.5)	
Cumulative Excess Cancer Risk, All Sites	8.76E-06 (10.5)					
All Fish						
PCBs	3.7E-06 (24.9)	9.4E-06 (9.8)	1.8E-05 (5.0)	2.5E-05 (3.8)	1.3E-05 (7.3)	1.8E-05 (5.2)
PCDDs/PCDFs	1.7E-07 (541.9)	2.4E-05 (3.8)	3.7E-06 (25.3)	7.8E-06 (11.9)	1.4E-05 (6.5)	6.5E-05 (1.4)
Cumulative Excess Cancer Risk	3.9E-06 (23.8)	3.4E-05 (2.7)	2.2E-05 (4.2)	3.2E-05 (2.9)	2.7E-05 (3.4)	8.3E-05 (1.1)
Cumulative Excess Cancer Risk, All Sites	3.6E-05 (2.6)					
All Species						
PCBs	3.6E-06 (25.3)	8.4E-06 (11.0)	1.8E-05 (5.3)	2.0E-05 (4.7)	1.6E-05 (5.8)	1.6E-05 (5.8)
PCDDs/PCDFs	1.7E-07 (541.9)	1.6E-05 (5.7)	3.7E-06 (25.3)	7.8E-06 (11.9)	1.4E-05 (6.5)	6.5E-05 (1.4)
Cumulative Excess Cancer Risk	3.8E-06 (24.2)	2.5E-05 (3.8)	2.1E-05 (4.4)	2.7E-05 (3.4)	3.0E-05 (3.1)	8.1E-05 (1.1)
Cumulative Excess Cancer Risk, All Sites	3.2E-05 (2.9)					

Table 7d. Theoretical lifetime excess cancer risk from consuming PCDFs/PCDDs, and/or PCBs in spotted seatrout collected in 2006 and 2007 from Lower Galveston Bay. Table 7d also provides suggested weekly eight-ounce meal consumption rates for 70-kg adults. [j]

Contaminant/ Site	**Theoretical Lifetime Excess Cancer Risk (Meals per Week)**									
	Hanna Reef	**Bolivar Spoil Island**	**Campbell Bayou**	**Snake Island**	**Dollar Point**	**Redfish Island**	**Galveston Jetties**	**Pelican Island**	**Offat's Bayou**	**Moses Lake**
PCBs	Spotted seatrout not collected	9.1E-06 (10.2)	1.9E-05 (4.8)	1.6E-05 (5.9)	1.5E-05 (6.2)	1.9E-05 (4.9)	7.0E-06 (13.1)	1.0E-05 (9.2)	1.5E-05 (6.0)	1.6E-05 (5.8)
PCDDs/PCDFs		5.8E-07 (160.4)	2.6E-06 (35.9)	No spotted seatrout samples analyzed	4.3E-05 (2.2)	9.5E-05 (1.0)	2.0E-08 (4606.1)	No spotted seatrout samples analyzed	No spotted seatrout samples analyzed	No spotted seatrout samples analyzed
Calculated Excess Lifetime Cancer Risk, all species		9.6E-06 (9.6)	2.2E-05 (4.2)		5.7E-05 (1.6)	**1.1E-04 (0.8)**	7.1E-06 (13.1)			
Calculated Excess Lifetime Cancer Risk, All Sites, All Species	4.3E-05 (2.2)									

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