Characterization of Potential Adverse Health Effects Associated with Consuming Fish from A Portion of Upper Galveston Bay

Chambers, Galveston, and Harris Counties, Texas

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LIST OF ACRONYMS

ADV	Fish and Shellfish Consumption Advisory
ATSDR	Agency for Toxic Substances and Disease Registry
BDL	Below Detection Limit
ca	Cancer
CDC	Centers for Disease Control
CW	Carapace Width
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DSHS	Department of State Health Services
g	Gram
GAL	Galveston Bay
GBEP	Galveston Bay Estuary Program
GC	Gas Chromatograph
GERG	Geochemical and Environmental Research Group
HAC	Health Assessment Comparison
HI	Hazard Index
HQ	Hazard Quotient
in	Inches
IRIS	Integrated Risk Information System
kg	Kilogram
lb	Pound
mg	Milligram
mm	Millimeter
MRL	Minimal Risk Level
MS	Mass spectrometer
n	Sample Size
ND	Not Detected
ng	Nanogram
nonca	Noncancer
PCB	Polychlorinated Biphenyl
PCDD	Polychlorinated Dibenzo-p-Dioxin
PCDF	Polychlorinated Dibenzofuran
pg	picogram
RfD	Reference Dose
RL	Reporting Limit
SALU	Seafood and Aquatic Life Unit
SH	State Highway
SVOC	Semivolatile Organic Compound
TCEQ	Texas Commission on Environmental Quality
TDH	Texas Department of Health
TEQ	Toxicity Equivalent

LIST OF ACRONYMS CONT.

TFCAV	Texas Fish Consumption Advisory Viewer
TL	Total Length
TNRCC	Texas Natural Resources Conservation Commission
TPWD	Texas Parks and Wildlife Department
UL	Tolerable Upper Intake Level
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound

SUMMARY

Galveston Bay hosts a robust recreational fishery and an economically import commercial fishery. In 2012, Texas Parks and Wildlife Department (TPWD) documented 16,470,070 pounds of commercially harvested seafood from Galveston Bay.[1] In 2016, recreational angling in Galveston Bay alone was estimated to contribute $87.2 million to Texas' gross domestic product, $55.7 million in labor income, and $152.1 million in sales of goods and services.[2] In addition, Galveston Bay is a shipping hub and is highly industrialized by petrochemical plants.[3] With much documented consumption of seafood from Galveston Bay and the risk of contamination from nearby industry, risk assessors sought to characterize the risks associated with eating seafood from Galveston Bay.

In 1986 the United States Environmental Protection Agency (USEPA) discovered dioxin congeners in fish and shellfish tissue collected in Upper Galveston Bay. In 1990, a Texas Department of Health (TDH) study found 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 and issued Fish and Shellfish Consumption Advisory 3 (ADV-3). Texas Department of State Health Services (DSHS) studies in 1994, 1996, and 1999, which included the portion of Upper Galveston Bay south of the State Highway 146 Bridge and all connected waters north of a line from Red Bluff Point to Five-Mile Cut Marker to Houston Point (hereafter referred to as Upper Galveston Bay, Figure 1), did not provide evidence to support lifting ADV-3. In 2006 and 2007, DSHS studies found gafftopsail catfish and spotted seatrout collected in Upper and Lower Galveston Bay contained dioxins and polychlorinated biphenyls (PCBs) at concentrations that exceeded DSHS guidelines for protection of human health, resulting in the issuance of Fish and Shellfish Consumption Advisory 35 (ADV-35).

In 2018-2019, the DSHS performed the current study to investigate any potential change in fish and crab tissue contamination in the aforementioned portion of Upper Galveston Bay (Figure 1). The present study examined fish and blue crab collected from Upper Galveston Bay in 2018 for the presence and concentrations of environmental toxicants that, if eaten, could potentially negatively affect human health. The study also addresses the public health implications of consuming fish and blue crabs from Upper Galveston Bay and suggests actions to reduce potential adverse health outcomes.

Results of the 2018 survey indicate that the combination of PCBs and PCDDs/PCDFs in gafftopsail catfish and spotted seatrout from Upper

Galveston Bay exceed DSHS guidelines for protection of human health. Concentrations of PCBs and PCDDs/PCDFs found in blue crab from Upper Galveston Bay no longer exceed DSHS guidelines for protection of human health. Confidence in the conclusions is limited by the small sample size. Sampling a small number of fish (i.e., individual species of fish or all fish species combined) decreases the confidence of mean contaminant concentrations for the fish population, thus adding uncertainty to the conclusions.

Recommendations

- People should not consume gafftopsail catfish from Upper Galveston Bay (Figure 1, Table 10).

- Women of childbearing age (women and girls under 50) including pregnant women, women who may become pregnant, and women who are nursing infants and children less than 12 years of age, or who weigh less than 75 pounds may consume up to two four-ounce meals per month of spotted seatrout from Upper Galveston Bay.

- Women past childbearing age (women 50 and older) and males 12 and older may consume up to two eight-ounce meals per month of spotted seatrout from Upper Galveston Bay.

- As resources become available, the DSHS should continue to monitor fish and crab from Galveston Bay to establish trends in contaminants of concern or for changes to contaminant concentrations that would require a change in consumption advice.

INTRODUCTION

This document summarizes the results of a survey of a portion of Upper Galveston Bay conducted in 2018 by the DSHS Seafood and Aquatic Life Unit (SALU).[a] The study, funded by the Galveston Bay Estuary Program (GBEP), a program of the Texas Commission on Environmental Quality and the USEPA, aimed to investigate any change in fish and crab tissue contamination in Galveston Bay fish. A total of 67 fish and crab samples from Galveston Bay underwent chemical analyses for environmental toxicants to determine if adverse health effects are likely following fish consumption (total expended $99,375). The report also addresses the public health implications of consuming fish from Upper Galveston Bay and suggests actions to reduce potential adverse health outcomes.

History of the Upper Galveston Bay Fish Consumption Advisory

In 1986, the USEPA, as part of the National Study of Chemical Residues in Fish[4], described the presence of dioxin congeners in fish and shellfish collected within USEPA Region 6. In 1990, the TDH[b] collected 12 fish and composite blue crab samples from the Houston Ship Channel and Upper Galveston Bay. Concentrations of PCDFs and PCDDs were found at levels that could pose a risk to human health. As such, Fish and Shellfish Consumption Advisory (ADV-3) was issued by TDH for the area of Galveston Bay north of a line connecting Red Bluff Point to Houston Point (by way of the Five Mile Cut marker) along with the Houston Ship Channel and its contiguous waters. In ADV-3, TDH advised children less than 12 and women of childbearing age not to consume catfish or blue crab from this advisory area[5].

The USEPA, through a Near Coastal Water Grant, funded a small study in 1994 that included fish and shellfish samples collected by DSHS from the Houston Ship Channel and Upper Galveston Bay. Results from this study indicated a slight decrease in PCDF/PCDD concentrations, but limited sample size disallowed any alteration to ADV-3.

In 1996, TDH collected fish, oyster and blue crab composite samples to re-evaluate ADV-3. Sample results from this study indicated a need to maintain the consumption advisory issued in ADV-3.

[a] The terms DSHS and SALU may be used interchangeably throughout this document and mean the same agency.

[b] Now the Department of State Health Services (DSHS)

In 1999, the Texas Natural Resource Conservation Commission (TNRCC)[c] funded a study of metals, PCBs (Aroclor 1260), pesticides, semivolatile organic compounds (SVOCs), and volatile organic compounds (VOCs) in fish and crabs collected from Upper Galveston Bay. Since samples were not evaluated for PCDF/PCDDs, the advisory for catfish and blue crabs remained in effect. With the exception of catfish, no restrictive finfish consumption advisory was issued as a result of the 1999 study.

In 2003-2004, GBEP received a grant from the USEPA under Section 104(b)(3) of the Clean Water Act. As a part of the first phase, risk associated with consumption of seafood from the Upper Galveston Bay area near La Porte was characterized in order to develop a Seafood Consumption Safety Program for the *Galveston Bay Plan* of the GBEP. Based on this data, ADV-3 was supported and spotted seatrout were additionally found to contain PCBs at levels exceeding DSHS Health Assessment Comparison (HAC) values. As a result, in 2005, DSHS issued Fish and Shellfish Consumption Advisory 28 (ADV-28) recommending 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.[6]

In 2006 and 2007, studies found gafftopsail catfish and spotted seatrout collected in Upper and Lower Galveston Bay contained PCDDs/PCDFs and PCBs at concentrations exceeding DSHS guidelines for protection of human health, resulting in the issuance of Fish and Shellfish Consumption Advisory 35 (ADV-35)[7]. Fish and Shellfish Consumption Advisory 49 (ADV-49)[8] and 50 (ADV-50)[9] rescinded ADV-3 and ADV-35 in 2013 following samples collected from the Galveston Bay Estuary. ADV-49 depicted risk associated with PCDF/PCDDs, organochlorine pesticides, and PCBs in the Houston Ship Channel and all contiguous water north of the Fred Hartman Bridge, SH 146. ADV-50 (Figure 2) depicted risk associated with PCDF/PCDDs and PCBs by separating Galveston Bay into Upper Galveston Bay and all contiguous waters north of a line from Red Bluff Point to Five Mile Cut Marker to Houston Point, and Galveston Bay and all contiguous waters including Chocolate Bay, East Bay, Trinity Bay and West Bay. Consumption advice for the Upper Galveston Bay region of ADV-50 include all species of catfish, spotted trout and blue crab. ADV-55 (Figure 2), issued in 2015, rescinded

[c] Now the Texas Commission of Environmental Quality (TCEQ)

ADV-49 to include PCDF/PCDDs and PCBs only, as organochlorine pesticide levels had dropped to acceptable levels.

METHODS

Fish Sampling, Preparation, and Analysis

The SALU collects edible fish from the state's public waters and evaluates the potential risks to the health of people consuming contaminated fish or shellfish. Fish tissue sampling follows standard operating procedures described in *Texas Fish Consumption Advisory Program Standard Operating Procedures Field Operations and Data Quality.*[10] The SALU bases its sampling and analysis protocols, in part, on procedures recommended by the USEPA's *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1.*[11] Advice and direction are also received from the Fish Sampling Advisory Subcommittee of the legislatively mandated Texas Toxic Substances Coordinating Committee.[12] Samples usually represent species, trophic levels, and legal-sized specimens available for consumption from a water body. When practical, the DSHS collects samples from two or more sites within a water body to better characterize geographical distributions of contaminants.

Fish Sampling Methods and Description of a portion of Upper Galveston Bay 2018 Sample Set

In April and May 2018, the SALU collected 9 blue crab composite and 58 fish samples from five sample sites (Figure 1): Site 1 Galveston Bay (GAL) at Red Bluff Point, Site 2 GAL at Houston Yacht Club, Site 3 GAL at Atkinson Island, Site 4 GAL at State Highway (SH) 146 Bridge, and Site 5 GAL at Tabbs Bay. Species collected represent distinct ecological groups (i.e., predators and bottom-dwellers) that have some potential to bio-accumulate chemical contaminants, have a wide geographic distribution, are of local recreational fishing value, and/or that anglers and their families commonly consume. Further, samples selected for this study followed species previously identified as containing contaminants at levels that could pose a risk to human health. The fish and blue crab collected from Upper Galveston Bay represent all species targeted for collection from this water body (Table 1). The following list contains the number of each target species collected for this study, listed in descending order: gafftopsail catfish (32); spotted seatrout (26); and blue crab composites (9).

The survey team set gill nets at sample sites 1–6[d] in late afternoon (Figure 1); fished the sites overnight and collected samples from the nets early the following morning. The gill nets were set at locations to maximize available cover and habitat at each sample site. 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. The survey team immediately stored samples on wet ice in large coolers to ensure interim preservation. Survey team members returned any live fish culled from the catch to the bay and properly disposed of samples found dead in the gill nets.

The SALU utilized hook and line sampling (a weighted popping cork with a swivel and 3/0 treble hook or 3/0 Kahle offset hook) to target spotted seatrout. The SALU staff baited lines with live shrimp and live croaker. The survey team targeted habitat likely to hold trout. Blue crab were collected by gillnets as well as baited crab traps.

The SALU staff processed fish at SALU Bacliff field office. Staff weighed each fish sample to the nearest gram (g) on an electronic scale (excluding composites) and measured total length (TL; tip of nose to tip of tail fin) to the nearest millimeter (mm; Table 1). For blue crab composite samples, individuals were measured for carapace width (CW; point to point) then added to other crab samples of similar size. All TL measurements were converted to inches (in) for use in this report. After weighing and measuring a fish, staff used a cutting board covered with aluminum foil and a fillet knife to prepare two skin-off fillets from each fish. For blue crab composites, carapace, gills and entrails were removed. The foil was changed and knife cleaned with distilled water after each sample was processed. The SALU staff wrapped fillet(s) or crab halves in two layers of fresh aluminum foil, which were placed in an unused, clean, pre-labeled plastic freezer bag, and stored on wet ice in an insulated chest until further processing. The SALU staff transported tissue samples on wet ice to their Austin, Texas headquarters, where the samples were stored temporarily (maximum=42 days) at -5° Fahrenheit (-20° Celsius) in a locked freezer. The freezer key is accessible only to authorized SALU staff members to ensure chain of custody while samples are in the possession of agency staff. The SALU delivered the frozen fish and crab tissue samples to the Geochemical and Environmental Research Group (GERG) Laboratory, Texas A&M University, College Station, Texas, for contaminant analysis.

Analytical Laboratory Information

[d] Sample Site 6 GAL at Black Duck Bay did not yield viable samples of target species.

The GERG personnel documented receipt of the 67 Upper Galveston Bay samples and recorded the condition of each sample along with its DSHS identification number. Using established USEPA methods,[13] the GERG laboratory analyzed fish fillets and crab composites from Upper Galveston Bay for inorganic and organic contaminants commonly identified in polluted environmental media. Analyses included seven metals (arsenic, cadmium, copper, lead, total mercury, selenium, and zinc), 123 SVOCs, 70 VOCs, 34 pesticides, 209 PCB congeners,[e, 14] and 17 PCDDs/PCDFs congeners. [15] The laboratory analyzed all 67 samples for PCBs and PCDDs/PCDFs. A subset of 10 of the original 67 samples were analyzed for the following contaminant groups: metals, pesticides, SVOCs, and VOCs. The SALU risk assessors selected the subset of samples based on target species, and historical data. In an effort to attain statistically valid data, and compare previous datasets, one species (gafftopsail catfish) was selected to represent the entire subset. In addition to SALU Standard Operating Procedures, if available, the SALU risk assessors used TPWD creel surveys to determine the species of fish most frequently harvested from the body of water and chose large specimens of the selected species of fish. The SALU risk assessors choose large fish to assess conservatively contaminant exposure when evaluating small sample sizes.

RESULTS

The GERG laboratory completed analyses and electronically transmitted the results of Upper Galveston Bay samples collected in April-May 2018 to the SALU in late May 2019. The laboratory reported the analytical results for metals, pesticides, PCBs, PCDDs/PCDFs, SVOCs, and VOCs.

For reference, Table 1 contains a list of fish samples collected by sample site. Tables 2.1–2.3 present the results of metals analyses. Tables 3.1–3.2 and 4.1–4.2 contain summary results for pesticides and PCBs, respectively. Tables 5.1–5.2 summarizes the PCDD/PCDF analyses. SVOC and VOC data is depicted in Tables 6 and 7 respectively. Unless otherwise stated, table summaries present the number of samples tested, the number of samples with detected concentrations of contaminants, the mean concentration and standard deviation, and the minimum and the maximum concentrations. In the tables, results may be reported as ND, below detection limit (BDL) for estimated concentrations or "J-values" below the reporting limit (RL), or as concentrations at or above the RL.

[e] A PCB congener is any single, unique well-defined chemical compound in the PCB category. The name of a congener specifies the total number of chlorine substituents and the position of each chlorine (e.g., 4,4' dichlorobiphenyl is a congener comprising the biphenyl structure with two chlorine substituents, one on each of the number 4 carbons of the two rings). In 1980, a numbering system was developed, which assigned a sequential number to each of the 209 PCB congeners.

Inorganic Contaminants

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

The GERG laboratory analyzed a subset of 10 gafftopsail catfish tissue samples for six inorganic contaminants. All tissue samples from Upper Galveston Bay contained concentrations of selenium and zinc (Tables 2.2). All concentration means are reported as mean $\pm$ standard deviation.

The SALU evaluated three toxic metalloids having no known human physiological function (arsenic, cadmium, and lead) in the samples collected from Upper Galveston Bay. Total arsenic concentrations ranged from 0.360 to 1.660 milligrams/kilogram(mg/kg) with a mean of 0.973±0.449 mg/kg (Table 2.1). Cadmium concentrations ranged from BDL to 0.100 mg/kg (Table 2.2). All lead concentrations were BDL.

Three of the metalloids analyzed are essential trace elements: copper, selenium, and zinc. Copper concentrations from BDL to 0.790 mg/kg (Table 2.2). Selenium concentrations ranged from 0.240 to 0.320 mg/kg with a mean of 0.258±0.041 mg/kg (Table 2.2). All samples also contained zinc. The mean zinc concentration in fish tissue samples from Upper Galveston Bay was 7.263±1.536 mg/kg (Table 2.2).

Mercury

All 10 gafftopsail catfish tissue samples evaluated from Upper Galveston Bay contained mercury. Mercury concentrations ranged from 0.186 to 0.425 mg/kg. The mean mercury concentration for the 10 fish tissue samples analyzed was 0.290±0.079 mg/kg (Table 2.3).

Organic Contaminants

Pesticides

All 10 gafftopsail catfish samples examined contained concentrations of chlordane, 4,4’- dichlorodiphenyldichloroethylene (DDE), 4,4’-dichlorodiphenyldichloroethane (DDD), dieldrin, and endrin. Chlordane (total) concentrations ranged from 0.0034 to 0.0397 mg/kg with a mean of 0.0136±0.0112 mg/kg (Table 3.1). DDT (total) [2,4’-DDE + 4,4’-DDE + 2,4’-DDD + 4,4’-DDD + 2,4’-DDT + 4,4’-DDT] ranged from 0.0065 to 0.0345 mg/kg with a mean of 0.0181±0.0091 mg/kg (Table 3.1). Dieldrin concentrations ranged from 0.0004 to 0.0064 mg/kg with a mean of 0.0021±0.0018 mg/kg (Table 3.1). Endrin concentrations were reported in

all 10 fish tissues samples analyzed, ranging from 0.0009 to 0.0160 mg/kg with a mean of 0.0037±0.0045 mg/kg (Table 3.1). Estimated to low concentrations greater than the reporting limit of hexachlorobenzene, and heptachlor epoxide were found in all samples (Table 3.2).

PCBs

All fish and crab tissue samples evaluated from Upper Galveston Bay contained PCBs (Tables 4.1–4.2). Across all sample sites and species, PCB concentrations ranged from 0.006 to 0.233 mg/kg. The mean PCB concentration for the 67 fish and crab tissue samples evaluated was 0.086±0.057 mg/kg.

Blue crab

Nine blue crab composite samples were analyzed for PCBs. One hundred percent of the blue crab samples (n=21) examined were of legal size (≥ 5 in CW).[16] PCB concentrations ranged from 0.006 to 0.020 mg/kg with a mean of 0.009±0.005 mg/kg (Tables 4.1–4.2).

Gafftopsail catfish

Thirty-two gafftopsail catfish ranging from 16.5 to 26.2 in TL (Table 1) were analyzed for PCBs. One hundred percent of the gafftopsail catfish samples examined were of legal size (≥ 14 in TL).[16] PCB concentrations ranged from 0.032 to 0.233 mg/kg with a mean of 0.122±0.056 mg/kg (Tables 4.1–4.2).

Spotted Seatrout

Twenty-six spotted seatrout ranging from 15.5 to 25.4 in TL (Table 1) were analyzed for PCBs. One hundred percent of the spotted seatrout samples examined were of legal size (≥ 15 in TL).[16] PCB concentrations ranged from 0.019 to 0.142 mg/kg with a mean of 0.068±0.027 mg/kg (Tables 4.1–4.2).

PCDDs/PCDFs

All 67 fish and crab tissue samples contained at least one of the 17 PCDD/PCDF congeners ranging from 0.060–9.540 TEQ picograms (pg)/g with a mean of 2.085±2.178 TEQ pg/g across all sites and species (Table 5.1–5.2). No samples contained all 17 congeners (data not shown). Gafftopsail catfish contained the highest mean PCDD/PCDF TEQ concentration (3.655±2.237 pg/g; Table 5.2). Spotted seatrout mean PCDD/PCDF TEQ concentration was 0.591±0.356 pg/g (Table 5.2). Blue crab mean PCDD/PCDF TEQ concentration was 0.821±0.650 pg/g (Table 5.2).

SVOCs

The GERG laboratory analyzed a subset of 10 gafftopsail catfish tissue samples for SVOCs. Quantifiable concentrations greater than the reporting limit were reported for benzoic acid and bis (2-ethylhexyl) phthalate in one fish sample. Estimated concentrations of benzoic acid, diethyl phthalate, and bis (2-ethylhexyl) phthalate were present in one or more fish samples analyzed (Table 6). The laboratory detected no other SVOCs in fish from Upper Galveston Bay.

VOCs

The Texas Fish Consumption Advisory Program Standard Operating Procedures Field Operations and Data Quality contain a complete list of the 70 VOCs selected for analysis. A subset of 10 gafftopsail catfish tissue samples was selected for analysis from Upper Galveston Bay. Trichlorofluoromethane concentrations ranged from BDL–0.090 mg/kg with a mean of 0.050±0.027 mg/kg (Table 7). Quantifiable concentrations greater than the reporting limit were reported for acetone, and methylene chloride in all fish samples.

Methylene chloride and acetone were also identified in one or more of the procedural blanks, suggesting that that this compound was introduced during sample preparation. VOC concentrations less than the reporting limit are difficult to interpret due to their uncertainty and may represent a false positive. The presence of many VOCs at concentrations less than the reporting limit may be the result of incomplete removal of the calibration standard from the adsorbent trap. VOC analytical methodology requires that the VOCs be thermally released from the adsorbent trap, transferred to the gas chromatograph (GC), and into the mass spectrometer (MS) for quantification.

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. Because 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, 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.**Error! Bookmark not defined.** 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 noncarcinogenic and carcinogenic endpoints in those who consume fish from Upper Galveston Bay. DSHS conclusions and recommendations to protect human health follow the discussion.

Characterization of Noncarcinogenic Health Effects from Consumption of Fish from Upper Galveston Bay

Inorganic Contaminants

None of the gafftopsail catfish evaluated contained arsenic, cadmium, copper, lead, mercury, selenium, or zinc at concentrations at or above DSHS guidelines for protection of human health.

Organic Contaminants

PCBs and PCDDs/PCDFs were observed in fish and crab from Upper Galveston Bay at concentrations at or above respective noncancer HAC ($HAC_{nonca)}$ (0.047 mg/kg; 1.630 pg/g; Tables 4.1–4.2, 5.1–5.2, and 8). None of the species of fish and crab evaluated contained any other organic contaminants at concentrations at or above DSHS guidelines for protection of human health.

PCBs

All fish and crab tissue samples (*n* = 67) evaluated contained PCBs. Over seventy percent of all samples analyzed contained PCB concentrations exceeding the HAC_{nonca} for PCBs (0.047 mg/kg; Tables 4.1–4.2). Two (gafftopsail catfish and spotted seatrout) of the three species of fish and crab evaluated had mean PCB concentrations exceeding the HAC_{nonca} for PCBs and a hazard quotient (HQ) exceeding 1.0 (Tables 4.1–4.2 and 8). The all fish combined mean PCB concentration (0.086 mg/kg) did exceed the HAC_{nonca} for PCBs and the HQ was greater than 1.0.

Meal consumption calculations are useful for risk managers to make fish consumption recommendations and/or take regulatory action. The SALU risk assessors calculated the number of eight-ounce meals of fish from Upper

Galveston Bay that healthy adults could consume without significant risk of PCB-related adverse noncarcinogenic effects (Table 8). Meal consumption rates were based on the overall mean PCB concentration by species. The SALU risk assessors estimated that healthy adults could consume less than one (0.4 to be exact) eight-ounce meal per week of gafftopsail catfish. The SALU risk assessors suggest that gafftopsail catfish and spotted seatrout from Upper Galveston Bay contain PCBs at concentrations that may pose potential noncarcinogenic health risks and that people should limit their consumption of both species from Upper Galveston Bay. Because the developing nervous system of the human fetus and young children may be especially susceptible to adverse noncarcinogenic health effects associated with consuming PCB-contaminated fish, the SALU risk assessors recommend more conservative consumption guidance for this sensitive subpopulation.

PCDDs/PCDFs

All 67 fish and crab tissue samples assayed contained PCDDs/PCDFs. 43% of all samples analyzed contained PCDD/PCDF concentrations exceeding the HAC_{nonca} for PCDDs/PCDFs (1.630 pg/g; Tables 5.1–5.2 and 8). One (gafftopsail catfish) of the three species of fish and crab evaluated had mean PCDD/PCDF concentrations exceeding the HAC_{nonca} for PCDDs/PCDFs and an HQ greater than 1.0 (Tables 5.1–5.2 and 8). The all fish combined mean PCDD/PCDF concentration exceeded the HAC_{nonca} for PCDDs/PCDFs and an HQ greater than 1.0. The consumption of gafftopsail catfish from Upper Galveston Bay may pose potential noncarcinogenic health risks from exposures to PCDDs/PCDFs.

The SALU risk assessors calculated the number of eight-ounce meals of fish from Upper Galveston Bay that healthy adults could consume without significant risk of PCDD/PCDF -related adverse systemic effects (Table 8). Meal consumption rates were based on the overall mean PCDD/PCDF concentration by species. The SALU risk assessors estimated that healthy adults could consume less than one eight-ounce meal per week of gafftopsail catfish (0.6 meals per week). The SALU risk assessors suggest that gafftopsail catfish from Upper Galveston Bay contain PCDDs/PCDFs at concentrations that may pose potential noncarcinogenic health risks and that people should limit their consumption. Because the developing nervous system of the human fetus and young children may be especially susceptible to adverse systemic health effects associated with consuming PCDD/PCDF-contaminated fish, the SALU risk assessors recommend more conservative consumption guidance for this sensitive subpopulation.

Characterization of Theoretical Lifetime Excess Cancer Risk from Consumption of Fish from Upper Galveston Bay

The USEPA classifies arsenic, most chlorinated pesticides, PCBs, and PCDDs/PCDFs as human carcinogens. Arsenic, chlordane, dieldrin, DDT (total), endrin, heptachlor epoxide, and hexachlorobenzene were present in gafftopsail catfish samples analyzed from Upper Galveston Bay, but none of these contaminants evaluated singly had mean contaminant concentrations that would be likely to increase the risk of cancer enough to exceed the DSHS guideline for protection of human health of one excess cancer in 10,000 equally exposed individuals. Cumulative risk for gafftopsail catfish collected from Upper Galveston Bay would be likely to increase the risk of cancer to exceed the DSHS guideline for protection of human health of one excess cancer in 10,000 equally exposed individuals. (Tables 9.1-9.2).

PCBs

The mean PCB concentrations observed in fish and crab from Upper Galveston Bay did not exceed the DSHS guideline for protection of human health of one excess cancer in 10,000 equally exposed individuals or the cancer HAC ($HAC_{ca)}$ for PCBs (0.272 mg/kg; Tables 4.1–4.2 and 9.1-9.2). Further, no PCB concentrations at or above the HAC_{ca} for PCBs were observed in fish or crab collected from Upper Galveston Bay. The all fish combined mean PCB concentration did not exceed the HAC_{ca} for PCBs.

PCDDs/PCDFs

The mean PCDD/PCDF concentrations observed in gafftopsail catfish exceed the DSHS guideline for protection of human health of one excess cancer in 10,000 equally exposed individuals or the HAC_{ca} for PCDDs/PCDFs (3.490 pg/g; Tables 5.1–5.2 and 9.1-9.2). The all fish combined mean PCDD/PCDF concentration exceeds the HAC_{ca} for PCDDs/PCDFs. The consumption of gafftopsail catfish from Upper Galveston Bay would be likely to increase the risk of cancer to exceed the DSHS guideline for protection of human health.

The SALU risk assessors calculated the number of eight-ounce meals of gafftopsail catfish from Upper Galveston Bay that healthy adults could consume without significantly increasing their lifetime excess cancer risk (Tables 9.1-9.2). The SALU risk assessors estimated that healthy adults could consume less than one eight-ounce meal per week of gafftopsail catfish (0.7 meals per week). Because children may experience effects at a lower exposure dose than adults because children's systems may be more sensitive to the effects of toxicants, the SALU risk assessors recommend more conservative consumption guidance for this sensitive subpopulation.

The SALU risk assessors suggest that consumption of gafftopsail catfish from Upper Galveston Bay would be likely to increase the risk of cancer to exceed the DSHS guideline for protection of human health from PCDD/PCDF exposure.

Characterization of Calculated Cumulative Noncarcinogenic Health Effects and of Cumulative Excess Lifetime Cancer Risk from Consumption of Fish and Crab from Upper Galveston Bay

Cumulative Noncarcinogenic Health Effects

Cumulative noncarcinogenic effects of toxicants may occur if more than one contaminant acts upon the same target organ or acts by the same mode or mechanism of action. PCBs and PCDDs/PCDFs in fish from Upper Galveston Bay could have these properties, especially with respect to effects on the immune system. Multiple organic contaminants in Upper Galveston Bay fish increased the likelihood of noncarcinogenic adverse health outcomes for all species of fish evaluated (Table 8). The combined toxicity of PCBs and PCDDs/PCDFs in gafftopsail catfish and spotted seatrout each exceeded a hazard index (HI; summed HQs) of 1.0.

The SALU risk assessors calculated the number of eight-ounce meals of fish from Upper Galveston Bay that healthy adults could consume without significant risk of PCB and/or PCDD/PCDF -related adverse systemic effects (Tables 8). Meal consumption rates were based on cumulative toxicity from exposure to PCBs and PCDDs/PCDFs by species. The SALU risk assessors estimated that healthy adults could consume less than one eight-ounce meal per week of gafftopsail catfish and spotted seatrout (Table 8). The SALU risk assessors suggest that gafftopsail catfish, and spotted seatrout from Upper Galveston Bay contain PCBs and PCDDs/PCDFs at concentrations that in combination may pose potential noncarcinogenic health risks and that people should limit their consumption of fish from Upper Galveston Bay. Because the developing nervous system of the human fetus and young children may be especially susceptible, the SALU risk assessors recommend more conservative consumption guidance for these sensitive subpopulations.

Cumulative Carcinogenic Health Effects

The SALU also queried the probability of increasing lifetime excess cancer risk from consuming fish containing multiple inorganic and organic contaminants. In most assessments of cancer risk from environmental exposures to chemical mixtures, researchers have considered any increase in cancerous or benign growths in one or more organs as cumulative, no matter the mode or mechanism of action of the contaminant. In this

assessment, risk assessors added the calculated carcinogenic effect of arsenic, chlorinated pesticides, PCBs, and PCDDs/PCDFs (Tables 9.1-9.2). In each instance, addition of the cancer risk for these chemicals increased the theoretical lifetime excess cancer risk. The cancer risk increase did elevate lifetime excess cancer risk to a level greater than the DSHS guideline for protection of human health of one excess cancer in 10,000 persons equivalently exposed for gafftopsail catfish from Upper Galveston Bay.

CONCLUSIONS

The SALU risk assessors prepare risk characterizations to determine public health hazards from consumption of fish and shellfish harvested from Texas water bodies by recreational or subsistence fishers. If necessary, the SALU risk assessors may suggest strategies for reducing risk to the health of those who may eat contaminated fish or seafood to risk managers at the DSHS, including the Texas Commissioner of Health.

This study addressed the public health implications of consuming fish from Upper Galveston Bay, located in Chambers, Galveston, and Harris Counties, Texas. Confidence in the conclusions for many species of fish and crab is limited by the small sample size. Sampling a small number of fish (i.e., individual species of fish or all fish species combined) decreases the confidence of mean contaminant concentrations for the fish population, thus adding uncertainty to the conclusions. Risk assessors from the SALU conclude from the present characterization of potential adverse health effects from consuming fish from Upper Galveston Bay that:

1. Blue crab mean concentrations of PCBs or PCDD/PCDF TEQs; either singly or in combination do not exceed the DSHS guidelines for protection of human health. Therefore, consumption of blue crab from Upper Galveston Bay containing PCBs and PCDD/PCDF **poses no apparent risk to human health**.

2. Gafftopsail catfish mean PCB concentrations and PCDD/PCDF TEQs exceed the DSHS guidelines for protection of human health. Regular or long-term consumption of gafftopsail catfish may result in adverse noncarcinogenic health effects and/or increase the likelihood of carcinogenic health risks. Therefore, consumption of gafftopsail catfish from Upper Galveston Bay containing PCBs and PCDD/PCDF **poses an apparent risk to human health**.

3. Spotted seatrout mean PCB concentrations exceed the DSHS guidelines for protection of human health. Regular or long-term consumption of spotted seatrout may result in adverse

noncarcinogenic health effects and/or increase the likelihood of carcinogenic health risks. Therefore, consumption of spotted seatrout from Upper Galveston Bay containing PCBs **poses an apparent risk to human health**.

Successes, Failures, and Lessons Learned

The analytic data for blue crab collected from Upper Galveston Bay in April and May of 2018 suggested that PCBs and PCDD/PCDFs no longer exceed the DSHS thresholds for protection of human health. As such, SALU recommends removal of blue crab from the Upper Galveston Bay advisory.

Chemical analysis of tissue is a costly endeavor. As such, sample size is often dictated by funding. DSHS was only able to analyze a subset of 10 samples out of the 67 samples collected for metals, pesticides, SVOC's and VOC's. In an effort to attain statistically valid data, and compare previous datasets, one species (gafftopsail catfish) was selected to represent the entire subset.

Portions of Galveston Bay were historically under fish and shellfish consumption advisories with risk attributed to legacy pesticides. Risk associated with pesticides (chlordane, total DDT, dieldrin, endrin, heptachlor epoxide, and hexachlorobenzene) was discovered to be insignificant in the 10 gafftopsail catfish analyzed. Further, no single pesticide exhibited greater than a 0.02 hazard quotient. Nevertheless, the uncertainty due to a void in pesticide data for blue crabs and spotted seatrout will be noted as a substantial shortcoming of this study. In the future, any re-evaluation should address all species, and all contaminants to the assessor's greatest ability.

The majority of risk associated with consumption of gafftopsail catfish and spotted seatrout is from PCBs. This finding is consistent with other studies conducted in Galveston Bay.

Between the time of sample collection by DSHS, and delivery of the chemical analysis of tissue samples by GERG, Galveston Bay and the Houston Ship Channel both experienced pollution events due to chemical spills that could cause adverse health effects to those who consume seafood from Upper Galveston Bay. The timeline, funding, and personnel requirements of a thorough and valid fish tissue contaminant study inhibit the ability of risk assessors and stakeholders to address every event that could potentially contribute risk associated with consumption of fish from a specified area.

RECOMMENDATIONS

Risk managers at the DSHS have established criteria for issuing fish consumption advisories based on approaches suggested by the USEPA.[11, 15, 17] Risk managers at the DSHS may decide to take action to protect public health if a risk characterization confirms that people can eat four or fewer meals per month (women past childbearing age [women 50 and older] and males 12 and older: eight-ounces per meal; women of childbearing age [women and girls under 50] and children less than 12: four-ounces per meal) of fish or shellfish from a water body under investigation. Risk management recommendations may be in the form of consumption advice or a ban on 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).[18] Declarations of prohibited harvesting areas are enforceable under the Texas Health and Safety Code, Subchapter D, parts 436.091 and 436.101.[18] The DSHS consumption advice carries no penalty for noncompliance. Consumption advisories, instead, inform the public of potential health hazards associated with consuming contaminated fish or shellfish from Texas waters. With this information, people can make informed decisions about whether and/or how much contaminated fish or shellfish they wish to consume. The SALU concludes from this risk characterization that consuming gafftopsail catfish and spotted seatrout from Upper Galveston Bay **poses an apparent hazard to public health.** Therefore, SALU risk assessors recommend that:

- People should not consume gafftopsail catfish from Upper Galveston Bay (Table 10).

- Women of childbearing age (Women and girls under 50) including pregnant women, women who may become pregnant, and women who are nursing infants and children less than 12 years of age, or who weigh less than 75 pounds may consume up to two four-ounce meals per month of spotted seatrout from Upper Galveston Bay (Table 10).

- Women past childbearing age (Women 50 and older) and males 12 and older may consume up to two eight-ounce meals per month of spotted seatrout from Upper Galveston Bay (Table 10).

- As resources become available, the DSHS should continue to monitor fish from Galveston Bay to establish trends in contaminants of concern and for changes to contaminant concentrations that would require a change in consumption advice.

PUBLIC HEALTH ACTION PLAN

Communication to the public of new and continuing possession bans or consumption advisories, or the removal of either, is essential to effective management of risk from consuming contaminated fish. In fulfillment of the responsibility for communication, the DSHS takes several steps.

- The SALU posts the most current information about advisories, bans, and the removal of either on the internet at http://www.dshs.texas.gov/seafood.[19] The SALU regularly updates this Website.
- The SALU also provides fish consumption advisory information through the Texas Fish Consumption Advisory Viewer (TFCAV; http://www.dshs.texas.gov/seafood/TFCAV.aspx). The TFCAV is an interactive map that allows users to identify current water body-specific health advisory information for fish from Texas waters.[20]
- DSHS publishes fish consumption advisories and bans in a booklet available to the public through the SALU Website (http://www.dshs.texas.gov/seafood/PDF2/HlthAdvisories/HealthAdvisoryGuide2016/). To receive the booklet and/or the data, please contact the SALU at 512-834-6757.[21]
- The DSHS also provides the USEPA (https://www.epa.gov/fish-tech), the TCEQ (http://www.tceq.texas.gov), and the TPWD (http://www.tpwd.texas.gov) with information on all consumption advisories and possession bans. Each year, the TPWD informs the public of consumption advisories and fishing bans on its Website and in an official downloadable PDF file containing general hunting and fishing regulations available at http://tpwd.texas.gov/regulations/outdoor-annual/. A booklet containing this information is available at all establishments selling Texas fishing licenses.[16]

Communication to the public of scientific information related to this risk characterization and information for environmental contaminants found in fish is essential to effective risk management. To achieve this responsibility for communication, the DSHS provides contact information to ask specific questions and/or resources to obtain more information about environmental contaminants in fish.

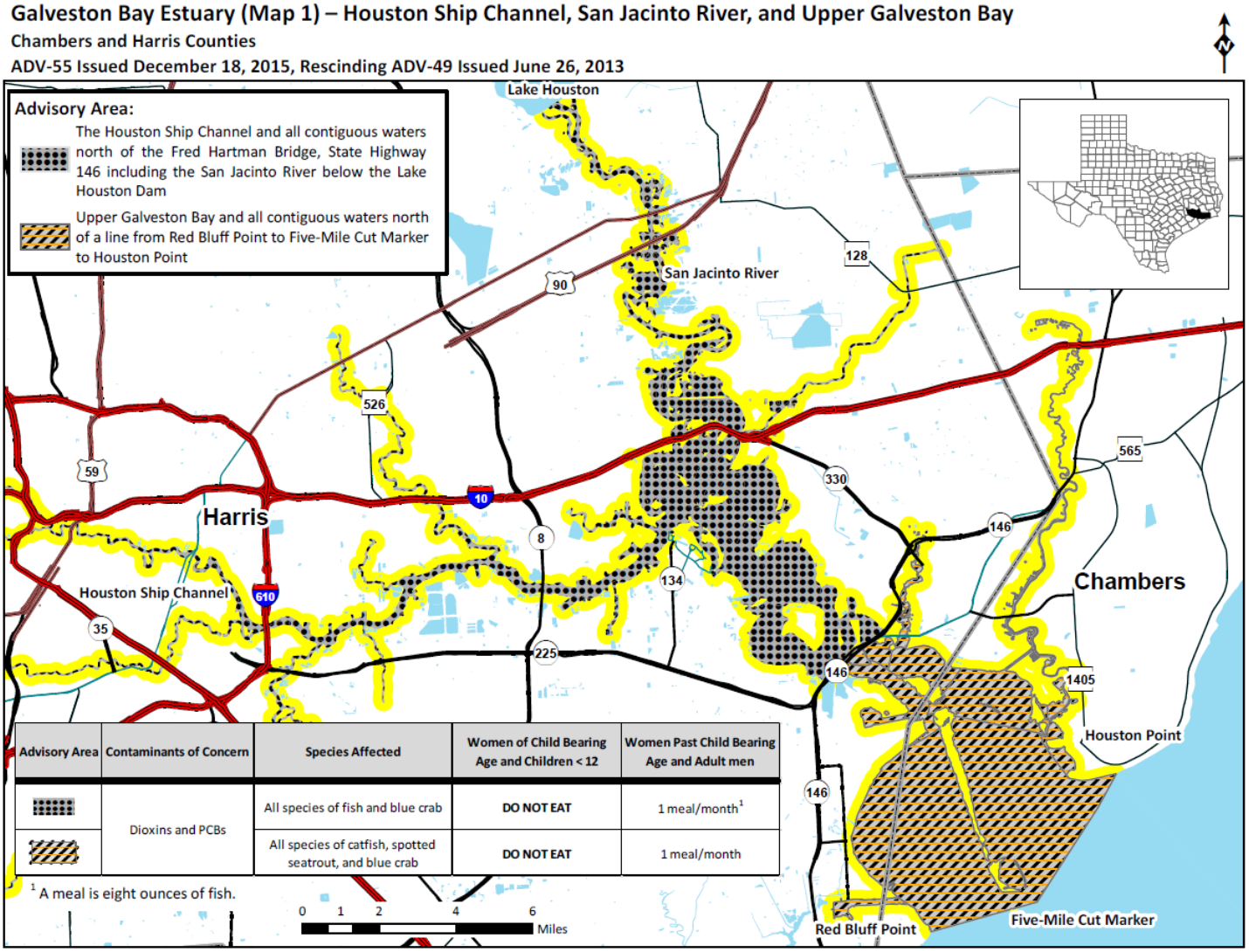
- Readers may direct questions about the scientific information or recommendations in this risk characterization to the SALU at 512-834-6757 or may find the information at the SALU's Website (http://www.dshs.texas.gov/seafood). Secondarily, one may address

inquiries to the Environmental and Injury Epidemiology and Toxicology Unit of DSHS (800-588-1248).

- The USEPA's Integrated Risk Information System (IRIS) Website (http://www.epa.gov/iris/) contains information on environmental contaminants found in food and environmental media.
- The Center for Disease Control's (CDC) Agency for Toxic Substances and Disease Registry (ATSDR), Division of Toxicology (888-42-ATSDR or 888-422-8737 or the ATSDR's Website (http://www.atsdr.cdc.gov) supplies brief information via ToxFAQs.™ ToxFAQs™ are available on the ATSDR Website in either English or Spanish (http://www.atsdr.cdc.gov/toxfaqs/index.asp). The ATSDR also publishes more in-depth reviews of many toxic substances in its *Toxicological Profiles* (ToxProfiles™) http://www.atsdr.cdc.gov/toxprofiles/index.asp. To request a copy of the ToxProfiles™ CD-ROM, Public Health Statement, or ToxFAQs™ call 1-800-CDC-INFO (800-232-4636) or email a request to cdcinfo@cdc.gov.

Figure 1. Upper Galveston Bay Map

Figure 2. Current Upper Galveston Bay Advisory Map



TABLES

Table 1. Fish samples collected from Galveston Bay 2018. Sample number, species, total length, and weight recorded for each sample.

Sample Number	Species	Total Length		Weight	
		Millimeters (mm)	Inches (in)	Grams (g)	Pounds (lb)
Site 1 Red Bluff Point					
GAL9	Spotted seatrout	538	21.2	1574	3.5
GAL10	Spotted seatrout	430	16.9	827	1.8
GAL11	Spotted seatrout	490	19.3	1210	2.7
GAL12	Spotted seatrout	482	19.0	1136	2.5
GAL13	Spotted seatrout	500	19.7	1356	3.0
GAL14	Spotted seatrout	469	18.5	1055	2.3
GAL15	Spotted seatrout	432	17.0	820	1.8
GAL16	Spotted seatrout	446	17.6	1011	2.2
GAL17	Spotted seatrout	432	17.0	868	1.9
GAL18	Spotted seatrout	428	16.9	821	1.8
GAL19	Spotted seatrout	417	16.4	825	1.8
GAL33	Gafftopsail catfish	560	22.0	1681	3.7
GAL34	Gafftopsail catfish	467	18.4	997	2.2
GAL35	Gafftopsail catfish	560	22.0	1648	3.6
GAL36	Blue crab	Composite[f]	Composite	Composite	Composite
GAL37	Gafftopsail catfish	665	26.2	2237	4.9
GAL66	Blue crab	Composite	Composite	Composite	Composite
GAL89	Spotted seatrout	407	16.0	671	1.5
GAL90	Spotted seatrout	645	25.4	1108	2.4
Site 2 Houston Yacht Club					
GAL1	Spotted seatrout	496	19.5	1209	2.7
GAL2	Spotted seatrout	415	16.3	772	1.7
GAL3	Spotted seatrout	440	17.3	963	2.1
GAL4	Spotted seatrout	394	15.5	622	1.4
GAL5	Spotted seatrout	463	18.2	1074	2.4
GAL6	Spotted seatrout	407	16.0	664	1.5
GAL7	Spotted seatrout	488	19.2	1321	2.9
GAL8	Spotted seatrout	430	16.9	838	1.8
GAL20	Spotted seatrout	411	16.2	785	1.7
GAL21	Spotted seatrout	411	16.2	794	1.8
GAL22	Spotted seatrout	405	15.9	679	1.5
GAL23	Spotted seatrout	436	17.2	1043	2.3
GAL24	Blue crab	Composite	Composite	Composite	Composite

[f] Composite samples consist of multiple individuals of the same species, utilized to comprise a sufficient quantity of tissue for chemical analysis.

Table 1. cont. Fish samples collected from Galveston Bay 2018. Sample number, species, total length, and weight recorded for each sample.

Sample Number	Species	Total Length		Weight	
		Millimeters (mm)	Inches (in)	Grams (g)	Pounds (lb)
Site 2 Houston Yacht Club cont.					
GAL25	Blue crab	Composite[g]	Composite	Composite	Composite
GAL26	Gafftopsail catfish	540	21.3	1628	3.6
GAL27	Gafftopsail catfish	599	23.6	1999	4.4
GAL28	Gafftopsail catfish	530	20.9	1400	3.1
GAL29	Gafftopsail catfish	439	17.3	760	1.7
GAL43	Gafftopsail catfish	604	23.8	2176	4.8
GAL44	Gafftopsail catfish	541	21.3	1659	3.7
GAL45	Gafftopsail catfish	574	22.6	1847	4.1
GAL46	Gafftopsail catfish	599	23.6	2155	4.8
GAL47	Gafftopsail catfish	573	22.6	2147	4.7
GAL48	Gafftopsail catfish	580	22.8	2202	4.9
GAL49	Gafftopsail catfish	585	23.0	1995	4.4
GAL50	Gafftopsail catfish	606	23.9	1782	3.9
GAL51	Gafftopsail catfish	571	22.5	1558	3.4
GAL52	Gafftopsail catfish	550	21.7	1577	3.5
GAL53	Gafftopsail catfish	547	21.5	1802	4.0
GAL54	Gafftopsail catfish	538	21.2	1464	3.2
GAL55	Gafftopsail catfish	554	21.8	1440	3.2
GAL56	Gafftopsail catfish	581	22.9	1962	4.3
GAL57	Gafftopsail catfish	559	22.0	2030	4.5
GAL58	Gafftopsail catfish	584	23.0	2058	4.5
GAL59	Gafftopsail catfish	550	21.7	1798	4.0
GAL60	Gafftopsail catfish	549	21.6	1525	3.4
GAL61	Gafftopsail catfish	584	23.0	1010	2.2
GAL62	Gafftopsail catfish	602	23.7	1926	4.2
GAL65	Gafftopsail catfish	420	16.5	638	1.4
GAL88	Spotted seatrout	452	17.8	888	2.0
GAL92	Blue crab	Composite	Composite	Composite	Composite

[g] Composite samples consist of multiple individuals of the same species, utilized to comprise a sufficient quantity of tissue for chemical analysis.

Table 1. cont. Fish samples collected from Galveston Bay 2018. Sample number, species, total length, and weight recorded for each sample.

Sample Number	Species	Total Length		Weight	
		Millimeters (mm)	Inches (in)	Grams (g)	Pounds (lb)
Site 3 Atkinson Island					
GAL93	Blue crab	Composite[h]	Composite	Composite	Composite
GAL94	Blue crab	Composite	Composite	Composite	Composite
GAL95	Blue crab	Composite	Composite	Composite	Composite
Site 4 SH 146 Bridge					
GAL73	Blue crab	Composite	Composite	Composite	Composite
GAL85	Gafftopsail catfish	554	21.8	1901	4.2
GAL86	Gafftopsail catfish	542	21.3	1776	3.9
GAL87	Gafftopsail catfish	591	23.3	2044	4.5

[h] Composite samples consist of multiple individuals of the same species, utilized to comprise a sufficient quantity of tissue for chemical analysis.

Table 2.1. Arsenic (mg/kg) in Gafftopsail catfish collected from Galveston Bay, 2018.

Species	Number Detected/ Number Tested	Total Arsenic Mean ± S.D. (Min-Max)	Inorganic Arsenic Mean[i]	HAC Value (nonca) and HAC Value (ca; mg/kg)[j]	Basis for Comparison Value
Gafftopsail catfish	10/10	0.973±0.449 (0.360-1.660)	0.097	0.700 0.363	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

Table 2.2. Trace metals in Gafftopsail catfish collected from Galveston Bay, 2018.

Species	Number Detected/ Number Tested	Mean ± S.D. (Min-Max)	HAC Value (nonca; mg/kg)	Basis for Comparison Value
Cadmium (mg/kg)				
Gafftopsail catfish	10/10	0.055±0.016 (BDL-0.100)	0.233	ATSDR Chronic Oral MRL— 0.0001 mg/kg–day
Copper (mg/kg)				
Gafftopsail catfish	10/10	0.490±0.147 (BDL-0.790)	334	Based on the Tolerable Upper Intake Level (UL) — 0.143 mg/kg–day[k]
Lead (mg/kg)				
Gafftopsail catfish	10/10	BDL	N/A	N/A
Selenium (mg/kg)				
Gafftopsail catfish	10/10	0.258±0.041 (0.240-0.320)	6	EPA Chronic Oral RfD — 0.005 mg/kg–day ATSDR Chronic Oral MRL — 0.005 mg/kg–day 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)[l, 22]
Zinc (mg/kg)				
Gafftopsail catfish	10/10	7.263±1.536 (5.150-9.750)	700	EPA Chronic Oral RfD — 0.3 mg/kg–day

[i] Most arsenic in fish and shellfish occurs as organic arsenic, considered virtually nontoxic. For risk assessment calculations, DSHS assumes that total arsenic is composed of 10% inorganic arsenic in fish and shellfish tissues.
[j] Derived from the MRL or RfD for noncarcinogens or the EPA slope factor for carcinogens; assumes a body weight of 70 kg, and a consumption rate of 30 grams per day, and assumes a 30-year exposure period for carcinogens and an excess lifetime cancer risk of $1x10^{-4}$.

[k] The Food and Nutrition Board, Institute of Medicine, National Academies UL for copper is 10 mg/day.
[l] The DSHS applied relative source contribution methodology (RSC) developed by EPA to derive a HAC value for selenium. DSHS risk assessor's assumed that 50% of the daily selenium intake is from other foods or supplements (≈ 200 µg/day for a 70 kg adult or one-half the RfD) and subtracted an amount equal to 50% of the RfD from the RfD to account for other sources of exposure to selenium. The remainder of the RfD, 0.0025 mg/kg/day, was utilized to calculate the HAC value for selenium.

Table 2.3. Mercury (mg/kg) in fish Gafftopsail catfish collected from Galveston Bay by sample site, 2018.				
Species	**Number Detected/ Number Tested**	**Mean ± S.D. (Min-Max)**	**HAC Value (nonca; mg/kg)**	**Basis for Comparison Value**
Site 1 Red Bluff Point			0.7	ATSDR Chronic Oral MRL for Methylmercury — 0.0003 mg/kg–day
Gafftopsail catfish	2/2	0.325±0.142 (0.224-0.425)		
Site 2 Houston Yacht Club				
Gafftopsail catfish	5/5	0.269±0.077 (0.186-0.385)		
Site 4 SH 146 Bridge				
Gafftopsail catfish	3/3	0.302±0.061 (0.234-0.352)		
All Sample Sites				
Gafftopsail catfish	10/10	0.290±0.079 (0.186-0.425)		

Table 3.1. Pesticides (mg/kg) in Gafftopsail catfish collected from Galveston Bay by sample site, 2018.

Species	Number Detected/ Number Tested	Mean ± S.D. (Min-Max)	HAC Value (nonca) and HAC Value (ca; mg/kg)	Basis for Comparison Value
Chlordane (total)				
Red Bluff Point	2/2	0.0040±0.0008 (0.0034 -0.0046)	1.167 1.556	EPA Chronic Oral RfD — 0.0005 mg/kg–day EPA Oral Slope Factor — 0.35 per mg/kg–day
Houston Yacht Club	5/5	0.0092±0.0038 (0.0041 -0.0134)		
SH 146 Bridge	3/3	0.0274±0.0107 (0.0202 -0.0397)		
All sites combined	10/10	0.0136±0.0112 (0.0034 -0.0397)		
DDT (total)				
Red Bluff Point	2/2	0.0068±0.0004 (0.0065 -0.0071)	1.167 1.601	EPA Chronic Oral RfD — 5.0E-4 mg/kg–day EPA Oral Slope Factor — 3.4E-1 per (mg/kg)/day
Houston Yacht Club	5/5	0.0163±0.0045 (0.0102 -0.0206)		
SH 146 Bridge	3/3	0.0287±0.0054 (0.0239 -0.0345)		
All sites combined	10/10	0.0181±0.0091 (0.0065 -0.0345)		
Dieldrin				
Red Bluff Point	2/2	0.0005±0.0001 (0.0004 -0.0006)	0.117 0.034	EPA Chronic Oral RfD — 0.00005 mg/kg–day EPA Oral Slope Factor — 16 per (mg/kg)/day
Houston Yacht Club	5/5	0.0015±0.0007 (0.0009 -0.0023)		
SH 146 Bridge	3/3	0.0041±0.0020 (0.0027 -0.0064)		
All sites combined	10/10	0.0021±0.0018 (0.0004 -0.0064)		
Endrin				
Red Bluff Point	2/2	0.0010±0.0001 (0.0009 -0.0011)	0.700	EPA Chronic Oral RfD — 3.0E-4 (mg/kg)/day
Houston Yacht Club	5/5	0.0022±0.0008 (0.0011 -0.0031)		
SH 146 Bridge	3/3	0.0082±0.0068 (0.0039 -0.0160)		
All sites combined	10/10	0.0037±0.0045 (0.0009 -0.0160)		

Table 3.2. Pesticides (mg/kg) in Gafftopsail catfish collected from Galveston Bay by sample site, 2018.

Species	Number Detected/ Number Tested	Mean ± S.D. (Min-Max)	HAC Value (nonca) and HAC Value (ca; mg/kg)	Basis for Comparison Value
Heptachlor Epoxide				
Red Bluff Point	2/2	BDL	0.030 0.060	EPA Chronic Oral RfD — 1.3E-5 mg/kg–day EPA Oral Slope Factor — 9.1E+0 per (mg/kg)/day
Houston Yacht Club	5/5	0.0004±0.0002 (BDL -0.0006)		
SH 146 Bridge	3/3	0.0009±0.0001 (0.0008 -0.0010)		
All sites combined	10/10	0.0005±0.0003 (BDL -0.0010)		
Hexachlorobenzene				
Red Bluff Point	2/2	BDL	1.867 0.340	EPA Chronic Oral RfD — 8.0E-4 mg/kg–day EPA Oral Slope Factor — 1.6E+0 per (mg/kg)/day
Houston Yacht Club	5/5	0.0005±0.0003 (BDL -0.0008)		
SH 146 Bridge	3/3	0.0022±0.0001 (0.0021 -0.0023)		
All sites combined	10/10	0.0009±0.0009 (BDL -0.0023)		

Table 4.1. PCBs (mg/kg) in fish collected from Galveston Bay by sample site, 2018.

Species	Number Detected/ Number Tested	Mean ± S.D. (Min-Max)	HAC Value (nonca) and HAC Value (ca; mg/kg)	Basis for Comparison Value
Site 1 Galveston Bay at Red Bluff Point				
Blue crab	2/2	0.007±0.001 (0.006-0.008)	0.047 0.272	EPA Chronic Oral RfD for Aroclor 1254 — 0.00002 mg/kg–day EPA Slope Factor — 2.0 per mg/kg–day
Gafftopsail catfish	4/4	**0.099**[m]±0.033 (**0.068**-**0.146**)		
Spotted seatrout	13/13	**0.060**±0.021 (0.019-**0.095**)		
All fish combined	19/19	**0.063**±0.033 (0.006-**0.146**)		
Site 2 Galveston Bay at Houston Yacht Club				
Blue crab	3/3	0.006±0.001 (0.006-0.007)	0.047 0.272	EPA Chronic Oral RfD for Aroclor 1254 — 0.00002 mg/kg–day EPA Slope Factor — 2.0 per mg/kg–day
Gafftopsail catfish	25/25	**0.114**±0.051 (0.032-**0.217**)		
Spotted seatrout	13/13	**0.077**±0.030 (0.043-**0.142**)		
All fish combined	41/41	**0.094**±0.052 (0.006-**0.217**)		
Site 3 Galveston Bay at Atkinson Island				
Blue crab	3/3	0.011±0.008 (0.006-0.020)	0.047 0.272	EPA Chronic Oral RfD for Aroclor 1254 — 0.00002 mg/kg–day EPA Slope Factor — 2.0 per mg/kg–day
Site 4 Galveston Bay at SH 146 Bridge				
Blue crab	1/1	0.012	0.047 0.272	EPA Chronic Oral RfD for Aroclor 1254 — 0.00002 mg/kg–day EPA Slope Factor — 2.0 per mg/kg–day
Gafftopsail catfish	3/3	**0.215**±0.024 (**0.188**-**0.233**)		
All fish combined	4/4	**0.165**±0.104 (0.012-**0.233**)		

[m] Emboldened numbers denote that PCB concentrations equal and/or exceed the DSHS HAC value for PCBs.

Table 4.2. PCBs (mg/kg) in fish collected from Galveston Bay by species, 2018.				
Species	**Number Detected/ Number Tested**	**Mean ± S.D. (Min-Max)**	**HAC Value (nonca) and HAC Value (ca; mg/kg)**	**Basis for Comparison Value**
Blue crab	9/9	0.009±0.005 (0.006-0.020)	0.047	EPA Chronic Oral RfD for Aroclor 1254 — 0.00002 mg/kg–day EPA Slope Factor — 2.0 per mg/kg–day
Gafftopsail catfish	32/32	**0.122**[n]±0.056 (0.032-**0.233**)		
Spotted seatrout	26/26	**0.068**±0.027 (0.019-**0.142**)	0.272	
All fish combined	67/67	**0.086**±0.057 (0.006-**0.233**)		

[n] Emboldened numbers denote that PCB concentrations equal and/or exceed the DSHS HAC value for PCBs.

Table 5.1 PCDDs/PCDFs toxicity equivalent (TEQ) concentrations (pg/g) in fish collected from Galveston Bay by sample site, 2018.

Species	Number Detected/ Number Tested	Mean ± S.D. (Min-Max)	HAC Value (nonca) and HAC Value (ca; ng/kg)	Basis for Comparison Value
Site 1 Galveston Bay at Red Bluff Point				
Blue crab	2/2	0.675±0.120 (0.590-0.760)	1.63	EPA RfD of 7.0×10^{-10} mg/kg/day
Gafftopsail catfish	4/4	**2.822°**±2.301 (1.120-**6.220**)		
Spotted seatrout	13/13	0.469±0.358 (0.060-1.100)	3.49	EPA Slope Factor — 1.56×10^{5} per mg/kg–day
All fish combined	19/19	0.986±1.386 (0.060-**6.220**)		
Site 2 Galveston Bay at Houston Yacht Club				
Blue crab	3/3	0.623±0.357 (0.360-1.030)	1.63	EPA RfD of 7.0×10^{-10} mg/kg/day
Gafftopsail catfish	25/25	**3.136**±1.302 (0.980-**5.890**)		
Spotted seatrout	13/13	0.712±0.321 (0.190-1.320)	3.49	EPA Slope Factor — 1.56×10^{5} per mg/kg–day
All fish combined	41/41	**2.184**±1.583 (0.190-**5.890**)		
Site 3 Galveston Bay at Atkinson Island				
Blue crab	3/3	0.890±1.112 (0.090-**2.160**)	1.63 3.49	EPA RfD of 7.0×10^{-10} mg/kg/day EPA Slope Factor — 1.56×10^{5} per mg/kg–day
Site 4 Galveston Bay at SH 146 Bridge				
Blue crab	1/1	1.500	1.63	EPA RfD of 7.0×10^{-10} mg/kg/day
Gafftopsail catfish	3/3	**9.087**±0.533 (**8.500**-**9.540**)		
All fish combined	4/4	**7.190**±3.818 (1.500-**9.540**)	3.49	EPA Slope Factor — 1.56×10^{5} per mg/kg–day

° Emboldened numbers denote that PCDDs/PCDFs concentrations equal and/or exceed the DSHS HAC value for PCDDs/PCDFs.

Table 5.2. PCDDs/PCDFs toxicity equivalent (TEQ) concentrations (pg/g) in fish collected from Galveston Bay by species, 2018.				
Species	**Number Detected/ Number Tested**	**Mean ± S.D. (Min-Max)**	**HAC Value (nonca) and HAC Value (ca; ng/kg)**	**Basis for Comparison Value**
Blue crab	9/9	0.821±0.650 (0.090-**2.160**[p])	1.63	EPA RfD of 7.0 x 10^{-10} mg/kg/day
Gafftopsail catfish	32/32	**3.655**±2.237 (0.980-**9.540**)		
Spotted seatrout	26/26	0.591±0.356 (0.060-1.320)	3.49	EPA Slope Factor — 1.56 x 10^{5} per mg/kg–day
All fish combined	67/67	**2.085**±2.178 (0.060-**9.540**)		

Table 6. Semivolatile organic compounds (mg/kg) in fish collected from the Upper Galveston Bay, 2018.				
Species	**Number Detected/ Number Tested**	**Mean ± S.D. (Min-Max)**	**HAC Value (nonca; mg/kg)**	**Basis for Comparison Value**
Benzoic acid				
Gafftopsail catfish	9/10	0.055±0.016 (BDL -0.101)	9333.333	EPA Chronic Oral RfD — 4.0E+0 mg/kg–day
Bis (2-ethylhexyl) phthalate				
Gafftopsail catfish	9/10	0.059±0.028 (ND -0.138)	N/A	N/A
Diethyl phthalate				
Gafftopsail catfish	10/10	BDL±0.000 (BDL -BDL)	N/A	N/A

[p] Emboldened numbers denote that PCDDs/PCDFs concentrations equal and/or exceed the DSHS HAC value for PCDDs/PCDFs.

Table 7. Volatile organic compounds (mg/kg) in fish collected from the Upper Galveston Bay, 2018.				
Species	**Number Detected/ Number Tested**	**Mean ± S.D. (Min-Max)**	**HAC Value (nonca; mg/kg)**	**Basis for Comparison Value**
Acetone				
Gafftopsail catfish	10/10	0.144±0.082 (BDL -0.264)	700	EPA Chronic Oral RfD — 3.0E-1 (mg/kg)/day
Methylene chloride				
Gafftopsail catfish	10/10	0.016±0.027 (0.013 -0.021)	700	EPA Chronic Oral RfD — 3.0E-1 (mg/kg)/day
Trichlorofluoromethane				
Gafftopsail catfish	10/10	0.050±0.027 (BDL -0.090)	700	EPA Chronic Oral RfD — 3.0E-1 (mg/kg)/day

Table 8. Hazard quotients (HQs) and hazard indices (HIs) for PCBs and/or PCDDs/PCDFs in fish collected from Galveston Bay in 2018. Table 8 also provides suggested weekly eight-ounce meal consumption rates for 70-kg adults.[q]			
Contaminant/Species	**Number of Samples**	**Hazard Quotient**	**Meals per Week**
Blue crab			
PCBs	9	0.19	4.8
PCDDs/PCDFs		0.50	1.8
Hazard Index (meals per week)		0.68	1.4
Gafftopsail catfish			
PCBs	32	**2.62[r]**	**0.4[s]**
PCDDs/PCDFs		**1.63**	**0.6**
Hazard Index (meals per week)		**4.25**	**0.2**
Spotted seatrout			
PCBs	26	**1.46**	**0.6**
PCDDs/PCDFs		0.36	11.1
Hazard Index (meals per week)		**1.83**	**0.5**
All fish and shellfish			
PCBs	67	**1.84**	**0.5**
PCDDs/PCDFs		**1.28**	**0.7**
Hazard Index (meals per week)		**3.12**	**0.3**

[q] DSHS assumes that children under 12 years of age and/or those that weigh less than 35 kg eat four-ounce meals.
[r] Emboldened numbers denote that the HQ or HI is ≥ 1.0.
[s] Emboldened numbers denote that the calculated allowable meals for an adult are ≤ 1.0 meal per week.

Table 9.1. Calculated theoretical lifetime excess cumulative cancer risk from consuming fish collected in 2018 from Galveston Bay containing carcinogens and suggested consumption rate (eight-ounce meals/week) for 70 kg adults who regularly eat fish from Galveston Bay over a 30-year period.[t]

Species/Contaminant	Number of Samples	Theoretical Lifetime Excess Cancer Risk		Meals per Week
		Risk	Population Size that Would Result in One Excess Cancer	
Blue crab				
PCBs	9	3.3E-06	302,469	unrestricted[u]
PCDDs/PCDFs		2.4E-05	42,504	3.9
Cumulative Cancer Risk		2.7E-05	37,680	3.5
Gafftopsail catfish				
Arsenic	10	1.7E-06	604,938	2.1
Chlordane		3.02E-7	3,309,693	unrestricted
Dieldren		8.8E-07	1,134,259	unrestricted
DDT		3.93E-07	2,541,757	unrestricted
PCBs	32	4.5E-05	22,295	2.1
PCDDs/PCDFs		7.6E-05	13,096	1.2
Cumulative Cancer Risk		**1.2E-04[v]**	**8,036**	**0.7[w]**

Table 9.2. Calculated theoretical lifetime excess cumulative cancer risk from consuming fish collected in 2018 from Galveston Bay containing carcinogens and

[t] DSHS assumes that children under 12 years of age and/or those who weigh less than 35 kg eat 4-ounce meals.
[u] Denotes that the allowable eight-ounce meals per week are > 16.0.
[v] Emboldened numbers denote calculated excess lifetime cancer risk after 30 years exposure is greater than 1.0E-04.
[w] Emboldened numbers denote that the calculated allowable meals for an adult are ≤ 1.0 meal per week.

suggested consumption rate (eight-ounce meals/week) for 70 kg adults who regularly eat fish from Galveston Bay over a 30-year period.[x]				
Species/Contaminant	**Number of Samples**	**Theoretical Lifetime Excess Cancer Risk**		**Meals per Week**
		Risk	**Population Size that Would Result in One Excess Cancer**	
Spotted seatrout				
PCBs	26	2.5E-05	39,857	3.7
PCDDs/PCDFs		1.7E-05	59,073	5.5
Cumulative Cancer Risk		4.2E-05	23,799	2.2
All fish				
Arsenic	10	1.7E-06	604,938	2.1
Chlordane		3.02E-7	3,309,693	unrestricted
Dieldren		8.8E-07	1,134,259	unrestricted
DDT		3.93E-07	2,541,757	unrestricted
PCBs	67	3.2E-05	31,691	2.9
PCDDs/PCDFs		6.0E-05	16,737	1.5
Cumulative Cancer Risk		**9.5E-05[y]**	**10,578**	**1.0[z]**

[x] DSHS assumes that children under 12 years of age and/or those who weigh less than 35 kg eat 4-ounce meals.
[y] Emboldened numbers denote calculated excess lifetime cancer risk after 30 years exposure is greater than 1.0E-04.
[z] Emboldened numbers denote that the calculated allowable meals for an adult are ≤ 1.0 meal per week.

Table 10. SALU recommended fish consumption advice for Upper Galveston Bay, 2018.

Contaminants of Concern	Species	Women of childbearing age and children < 12	Women past childbearing age and males 12 and older
PCDDs/PCDFs and PCBs	Gafftopsail catfish	**DO NOT EAT**	**DO NOT EAT**
	Spotted seatrout	2 meals/month	2 meals/month

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