Characterization of Potential Adverse Health Effects Associated with Consuming Fish from the

Northwestern Gulf of Mexico

(nearshore and offshore waters of Texas)

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INTRODUCTION

This document summarizes the results of a survey of nearshore and offshore waters of Texas (northwestern Gulf of Mexico; NWGOM) conducted in the summer of 2011 by the Texas Department of State Health Service (DSHS) Seafood and Aquatic Life Group (SALG). Over 1.1 million people participate in saltwater fishing activities in Texas annually.[1] Recreational saltwater fishing in Texas represents a $1.8 billion per year industry. Previous studies have documented mercury concentrations in many nearshore and offshore fish throughout the NWGOM that are a potential public health issue.[2] In 1997, the DSHS issued a mercury advisory for king mackerel recommending population and size-specific consumption advice due to mercury contamination. To this end, the king mackerel advisory represents DSHS' only investigation of nearshore and/or offshore fish. Due to the lack of mercury fish tissue data, the DSHS has not had the ability to adequately characterize health risks associated with consumption of nearshore and offshore fish. This project will begin to assess the potential mercury related human health risks associated with consumption of fish from nearshore and offshore waters of Texas. This report addresses the public health implications of consuming fish from the NWGOM and suggests actions to reduce potential adverse health outcomes.

Description of the Gulf of Mexico

The Gulf of Mexico (GOM) is located at the southeastern corner of North America and is bordered by the United States (U.S.) to the north, Mexico to the west, and Cuba to the southeast. The GOM measures approximately 995 miles east to west and 560 miles north to south and has a surface area of approximately 600,000 square miles.[3] Texas nearshore and offshore waters of the NWGOM extend for 367 miles from the Rio Grande delta to Sabine Pass.[4] The Gulf of Mexico basin resembles a large pit with a broad shallow rim. Approximately 38% of Gulf waters are shallow intertidal areas. The waters of the continental shelf (<200 m) and continental slope (200-3000 m) represent 22% and 20% respectively, and abyssal areas deeper than 3,000 m comprise the final 20%. The Loop Current circulates water throughout the GOM entering the GOM through the Yucatan Strait and exiting through the Florida Strait eventually forming the Gulf Stream. Portions of the Loop Current often break away forming eddies, which affect regional current patterns. Smaller wind driven and tidal currents are created in nearshore environments.[5] Drainage into the GOM is extensive and includes 20 major river systems (>150 rivers). Annual freshwater inflow to the GOM is approximately 280 trillion gallons per year. Eighty-five percent of this inflow comes from the U.S., with 64% originating from the Mississippi River alone. Additional freshwater inputs originate in Mexico, the Yucatan Peninsula, and Cuba. The GOM ecosystem provides many resources to the nations on its shores. The GOM fisheries are some of the most productive in the world. In 2010, according to the National Marine Fisheries Service, the estimated commercial fish and shellfish harvest from the five U.S. Gulf states was 1.3 billion pounds valued at $639 million. The GOM also supports a productive recreational fishery. In 2010, marine recreational fishers took more than 20.7 million trips catching 145.4 million fish (> 59.3 million pounds) from the GOM. The offshore petroleum industry employs over 55,000 U.S. workers in the GOM. According to the Minerals Management Service, offshore operations in the GOM produce a quarter of the U.S. domestic natural gas and one-eighth of its oil. The GOM is also home to two of the ten busiest ports in the world by cargo volume (Port of South Louisiana (New Orleans) and the Port of Houston). Seven of the top ten seaports in the U.S. are located on the GOM. The GOM's shores and beaches support a $20 billion tourist industry offering swimming, sun, and all water sports.

Demographics of the Texas Gulf Coast

The Texas Gulf coast covers 18 counties divided into five areas: Southeast Texas (Jefferson and Orange Counties), Houston-Galveston (Brazoria, Chambers, Galveston, Harris, and Matagorda Counties), the Golden Crescent (Calhoun, Jackson, and Victoria Counties), the Coastal Bend (Aransas, Kleburg, Kenedy, Nueces, Refugio, and San Patricio Counties), and the Lower Rio Grande Valley (Cameron and Willacy Counties). The U.S. Census 2010 estimated the population of the 18 counties along the Texas Gulf coast at 6,121,490 people.[6] The Texas Gulf coast has five metropolitan statistical areas (MSAs) defined by the United States Census Bureau (USCB): Houston–Sugarland–Baytown (5,946,800 people; U.S. Census 2010), Corpus Christi (428,185), Brownsville–Harlingen (406,220), Beaumont–Port Arthur (388,745), and Victoria (115,384).

NWGOM Subsistence Fishing

The United States Environmental Protection Agency (USEPA) suggests that, along with ethnic characteristics and cultural practices of an area's population, the poverty rate could contribute to any determination of the rate of subsistence fishing in an area.[7] The USEPA and the DSHS find, in concert with the USEPA, it is important to consider subsistence fishing to occur at any water body because subsistence fishers (as well as recreational anglers and certain tribal and ethnic groups) usually consume more locally caught fish than the general population. These groups sometimes harvest fish or shellfish from the same water body over many years to supplement caloric and protein intake. Should local water bodies contain chemically contaminated fish or shellfish, people who routinely eat fish from the water body or those who eat large quantities of fish from the same waters, could increase their risk of adverse health effects. The USEPA suggests that states assume that at least 10% of licensed fishers in any area are subsistence fishers. Subsistence fishing, while not explicitly documented by the DSHS, likely occurs. The DSHS assumes the rate of subsistence fishing to be similar to that estimated by the USEPA.

METHODS

Fish Sampling, Preparation, and Analysis

The DSHS SALG collects and analyzes edible fish from the state's public waters to evaluate potential risks to the health of people consuming 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.*[8] The SALG 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.*[9] Advice and direction are also received from the legislatively mandated *State of Texas Toxic Substances Coordinating Committee (TSCC) Fish Sampling Advisory Subcommittee (FSAS).*[10] 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 the NWGOM 2011 Sample Set

In June–August 2011, the SALG staff collected 288 fish samples from the NWGOM. The SALG risk assessors used data from these fish to assess the potential for adverse human health outcomes from consuming fish from the NWGOM.

The SALG selected three ports or general areas as sample collection locations: Galveston offshore (GAO), Port O'Connor offshore (POO), and Port Aransas offshore (PAO; Figure 1). 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. The 288 fish collected from the Gulf of Mexico represent all species targeted for collection from this water body (Table 1). The list below contains the number of each target species collected for this study in descending order: king mackerel (71), red snapper (44), little tunny (27), dolphinfish (21), Spanish mackerel (21), blacktip shark (20), cobia (17), yellowfin tuna (13), tripletail (9), wahoo (9), blackfin tuna (8), Atlantic sharpnose shark (7), jack crevale (7), lane snapper (4), blue marlin (3), swordfish (3), mangrove snapper (2), bonnethead shark (1), and Warsaw grouper (1).

The SALG staff utilized hook-and-line sampling techniques to collect 255 fish samples for this project. The SALG staff immediately stored caught fish, selected as samples on wet ice in large insulated chests to ensure interim preservation. The SALG staff released any live fish culled from the catch or not selected as a fish sample for this project. The SALG also worked cooperatively with the organizers of three offshore sport-fishing tournaments (The Lonestar Shootout Port O'Connor, Texas, June 21–26, 2011; Poco Bueno Port O'Connor, Texas, July 12–17, 2011; and Texas Legends Billfish Tournament Port Aransas, Texas, August 8–14, 2011) to collect 33 fish samples for this project (Table 1).

The SALG staff processed all fish caught by SALG staff. The SALG staff weighed each sample to the nearest kilogram or pound (kg; lb) on an electronic scale and measured total length (TL: tip of nose to tip of tail fin) and girth (circumference at the widest part of the fish body anterior to the dorsal fin) to the nearest one-quarter inch (in). The SALG staff processed all fish samples collected from the three offshore fishing tournaments at the dock near the tournament weigh station. The SALG staff obtained each fish sample weight (lb) from the tournament weigh master and measured TL or fork length (FL: tip of nose to fork of tail fin) for blue marlin and swordfish only to the nearest one-quarter inch. After weighing and measuring each fish, SALG staff used a cutting board covered with aluminum foil and a fillet knife to prepare one skin-off fillet from each fish. The skin-off fillet consisted of a minimum 50-gram dorsal epaxial muscle tissue with skin removed. The foil was changed and the knife cleaned with distilled water after each sample was processed. The SALG staff wrapped each fillet in two layers of fresh aluminum foil, placed in an unused, clean, pre-labeled plastic freezer bag, and stored on wet ice in an insulated chest until further processing. The SALG staff transported tissue samples on wet ice to their Austin, Texas headquarters, where the samples were stored temporarily at -5° Fahrenheit (-20° Celsius) in a locked freezer. The freezer key is accessible only to authorized SALG staff members to ensure chain of custody while samples are in the possession of agency staff. The SALG delivered the frozen fish tissue samples to the DSHS Laboratory Service Section Austin, Texas, for mercury analysis.

Analytical Laboratory Information

Upon arrival of the fish samples at the laboratory, the DSHS Laboratory Service Section personnel documented receipt of the 288 NWGOM fish samples and recorded the condition of each sample along with its DSHS identification number. Using established USEPA methods, the DSHS laboratory analyzed 288 fish fillets from the NWGOM for mercury.[11]

Details of Mercury Analyses with Explanatory Notes

Nearly all mercury in upper trophic level fish three years of age or older is methylmercury.[12] Thus, the total mercury concentration in a fish of legal size for possession in Texas serves well as a surrogate for methylmercury concentration. Because methylmercury analyses are difficult to perform accurately and are more expensive than total mercury analyses, the USEPA recommends that states determine total mercury concentration in a fish and that – to protect human health – states conservatively assume that all reported mercury in fish or shellfish is methylmercury. The DSHS Laboratory Service Section thus analyzed fish tissues for total mercury. In its risk characterizations, The DSHS compares mercury concentrations in tissues to a comparison value derived from the Agency for Toxic Substances and Disease Registry's (ATSDR) minimal risk level (MRL) for methylmercury.[13] (In these risk characterizations, the DSHS may interchangeably utilize the terms "mercury," "methylmercury," or "organic mercury" to refer to methylmercury in fish).

Derivation and Application of Health-Based Assessment Comparison Values for Systemic Effects (HAC_{nonca}) 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, habits of the exposed, or the presence of other chemicals.[14] 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 may include cancer, benign tumors, birth defects, infertility, blood disorders, brain damage, peripheral nerve damage, lung disease, and kidney disease.[14]

If diverse species of fish or shellfish are available, the SALG presumes that people eat a variety of species from a water body. Further, SALG risk assessors assume that most fish species are mobile. SALG risk assessors may combine data from different fish species 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 a DSHS medical epidemiologist.[15] The SALG evaluates contaminants in fish or shellfish by comparing the mean or the 95% upper confidence limit on the mean 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 (kg) and consumes 30 grams (g) of fish or shellfish per day (about one eight-ounce meal per week) and uses the USEPA's oral reference doses (RfDs)[16] or the ATSDR's chronic oral minimal risk levels (MRLs).[17] 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.*[18]

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.*[18]

The ATSDR uses a similar technique to derive its MRLs.[17] The DSHS divides the estimated daily dose derived from the measured concentration in fish tissue by the contaminant's RfD or MRL to derive a hazard quotient (HQ). The USEPA defines a HQ as

> *…the ratio of the estimated exposure dose of a contaminant (mg/kg/day) to the contaminant's RfD or MRL (mg/kg/day).*[19]

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. A 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 a HQ or a hazard index (HI) – defined as the sum of HQs for contaminants to which an individual is exposed simultaneously – that computes to less than 1.0 should be interpreted as "no cause for concern" whereas, a HQ or HI greater than 1.0 "should indicate some cause for concern."

The SALG does not utilize HQs 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 qualitative measurement. Qualitatively, HQs less than 1.0 are unlikely to be an issue while HQs greater than 1.0 might suggest a regulatory action to ensure protection of public health. Similarly, risk assessors at the DSHS may utilize a 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 1.0 is unlikely to cause adverse systemic health effects, whereas routine consumption of fish or shellfish in which the HQ exceeds 1.0 represents a qualitatively unacceptable increase in the likelihood of systemic adverse health outcomes.

Although the DSHS utilizes chemical specific RfDs when possible, if an RfD is not available for a contaminant, the USEPA advises risk assessors to consider evaluating the contaminant by comparing it to the published RfD (or the MRL) of a contaminant of similar molecular structure or one with a similar mode or mechanism of action. For instance, Aroclor® 1260 has no RfD, so the DSHS uses the reference dose for Aroclor 1254 to assess the likelihood of systemic (noncarcinogenic) effects of Aroclor 1260.[17]

In developing oral RfDs and MRLs, federal scientists review the extant literature to devise NOAELs, LOAELs, or benchmark doses (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. These include extrapolation from animals to humans (interspecies variability), intra-human variability, and use of a subchronic study rather than a chronic study to determine the NOAEL, LOAEL, or BMD, and database insufficiencies.[16,18] 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 are considered sensitive populations by risk assessors and USEPA and also receive special consideration in calculation of a RfD.[18]

Children's Health Considerations

The DSHS recognizes that fetuses, infants, and children may be uniquely susceptible to the effects of toxic chemicals and suggests that exceptional susceptibilities demand special attention.[20, 21] Windows of special vulnerability (known as "critical developmental periods") exist during development. Critical periods occur particularly during early gestation (weeks 0 through 8) but can occur at any time during development (pregnancy, infancy, childhood, or adolescence) at times when toxicants can impair or alter the structure or function of susceptible systems.[22] Unique early sensitivities may exist after birth because organs and body systems are structurally or functionally immature at birth, continuing to develop throughout infancy, childhood, and adolescence. Developmental variables may influence the mechanisms or rates of absorption, metabolism, storage, or excretion of toxicants. Any of these factors could alter the concentration of biologically effective toxicant at the target organ(s) or could modulate target organ response to the toxicant. Children's exposures to toxicants may be more extensive than adults' exposures because children consume more food and liquids in proportion to their body weights than adults consume. Infants can ingest toxicants through breast milk, an exposure pathway that often goes unrecognized. Nonetheless, the advantages of breastfeeding outweigh the probability of significant exposure to infants through breast milk and women are encouraged to continue breastfeeding and to limit exposure of their infants by limiting intake of the contaminated foodstuff. Children may experience effects at a lower exposure dose than might adults because children's organs may be more sensitive to the effects of toxicants. Stated differently, children's systems could respond more extensively or with greater severity to a given dose than would an adult organ exposed to an equivalent dose of a toxicant. Children could be more prone to developing certain cancers from chemical exposures than are adults.[23] In any case, if a chemical or a class of chemicals is observed to be, or is thought to be, more toxic to fetuses, infants, or children, the constants (e.g., RfD, MRL, or Cancer Potency Factors [CPFs]) are usually modified further to assure the immature systems' potentially greater susceptibilities are not perturbed.[16] Additionally, in accordance with the ATSDR's *Child Health Initiative*[24] and the USEPA's *National Agenda to Protect Children's Health from Environmental Threats,*[25] 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. For instance, if the DSHS issues consumption advice that recommends consumption of no more than two meals per month of a contaminated species, those children should eat no more than 24 meals of the contaminated fish or shellfish per year and should not eat such fish or shellfish more than twice per month.

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), using SPSS® to generate descriptive statistics (mean, standard deviation, median, minimum and maximum concentrations, and range) on measured compounds.[26] In computing descriptive statistics, SALG risk assessors utilized ½ the reporting limit (RL) for analytes designated as not detected (ND) or estimated (J-values)[*]. The SALG used the descriptive statistics from the above calculations to generate the present report. The SALG risk assessors performed correlation and regression analyses to describe relationships between mercury concentration and total length (TL). When appropriate and as needed, the SALG risk assessors $\log_e$-transformed mercury concentrations to improve normality and best fit of the data. The SALG risk assessors used a *t*-test to examine differences in mercury concentrations in king mackerel by sampling event (1996–1997 and 2011) and mercury concentrations between two size classes (< 43 and > 43 inches TL). The SALG risk assessors also used univariate analysis of variance (ANOVA) to consider differences in mercury concentrations in king mackerel between the current three consumption advisory size classes (< 37, 37 to 43, and > 43 inches TL). Statistical significance was determined at $p \leq 0.05$ for all statistical analyses. The SALG employed Microsoft Excel® spreadsheets to generate figures, to compute HAC_{nonca} values for mercury, and to calculate HQs and meal consumption limits for fish from the NWGOM.[27]

[*] *"J-value" is standard laboratory nomenclature for analyte concentrations that are detected and reported below the reporting limit (<RL). 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.*

RESULTS

The DSHS laboratory completed analyses and electronically transmitted the results of the NWGOM samples collected in June–August 2011 to the SALG in October 2011. The laboratory reported the analytical results for mercury.

For reference, Table 1 contains the total number of samples collected. Tables 2a–2b present the results of mercury analyses. Unless otherwise stated, table summaries present the number of samples containing a specific contaminant/number tested, the mean concentration ± 1 standard deviation (68% of samples should fall within one standard deviation of the arithmetic 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 use the range may derive this statistic by subtracting the minimum concentration of a given contaminant from its maximum concentration. In the tables, results may be reported as ND, below detection limit (BDL) for estimated concentrations, or as measured concentrations. According to the laboratory's quality control/quality assurance materials, estimated concentrations reported as BDL rely upon the laboratory's method detection limit (MDL) or its reporting limit (RL). The MDL is the minimum concentration of an analyte that be reported with 99% confidence that the analyte concentration is greater than zero, while the RL is the concentration of an analyte reliably achieved within specified limits of precision and accuracy during routine analyses. Mercury concentrations reported below the RL are qualified as "J-values" in the laboratory data report.[28]

Mercury

Two-hundred eighty-one of 288 fish tissue samples evaluated from the NWGOM contained mercury (Tables 2a). Across all species, mercury concentrations ranged from ND (dolphinfish and tripletail) to 18.500 mg/kg (blue marlin). The mean mercury concentration for the 288 fish tissue samples assayed was 0.543±1.417 mg/kg (Table 2a).

The relationships between mercury concentration and TL were positive and significant (p <0.05) for six of 12 species (Figures 2–10). The SALG risk assessors did not include seven species (blue marlin, bonnethead shark, lane snapper, mangrove snapper, swordfish, tripletail, and Warsaw grouper) in these analyses due to insufficient sample size or more than 50% of the samples assayed contained ND mercury concentrations. TL explained from 19 to 96% of the variation in mercury concentration (Figures 2–10). Correlation was strongest for wahoo.

<u>Atlantic sharpnose shark</u>

Seven Atlantic sharpnose shark ranging from 34.00 to 38.75 inches TL ($\overline{X}$ – 36.6 inches TL) were analyzed for mercury (Table 1). One-hundred percent of the Atlantic sharpnose shark samples examined were of legal size (≥ 24 inches TL [Texas waters]; no length limit [federal waters]).[29, 30] Mercury concentrations ranged from 0.478 to 1.890 mg/kg with a mean of 0.899±0.533 and a median of 0.589 mg/kg (Tables 2a). The SALG risk assessors computed a Pearson product-moment correlation coefficient to assess the relationship between mercury concentration and TL. There was no correlation between the two variables (r = 0.514, n = 7, p = 0.238).

Blackfin tuna

Eight blackfin tuna ranging from 30.0 to 35.75 inches TL ($\overline{X}$ – 32.0 inches TL) were analyzed for mercury (Table 1). Currently, there is no length limit for blackfin tuna in Texas or federal waters.[29, 30] Mercury concentrations ranged from 0.409 to 1.120 mg/kg with a mean of 0.782±0.238 and a median of 0.746 mg/kg (Tables 2a). The SALG risk assessors computed a Pearson product-moment correlation coefficient to assess the relationship between mercury concentration and TL. There was no correlation between the two variables ($r = 0.503$, $n = 8$, $p = 0.204$).

Blacktip shark

Twenty blacktip shark ranging from 28.00 to 52.25 inches TL ($\overline{X}$ – 40.1 inches TL) were analyzed for mercury (Table 1). One-hundred percent of the blacktip shark samples examined were of legal size (≥ 24 inches TL [Texas waters]); The length limit for blacktip shark in federal waters is ≥ 54 inches FL.[29, 30] Mercury concentrations ranged from 0.053 to 0.508 mg/kg with a mean of 0.180±0.121 and a median of 0.133 mg/kg (Tables 2a). The SALG risk assessors computed a Pearson product-moment correlation coefficient to assess the relationship between mercury concentration and TL. There was no correlation between the two variables ($r = 0.281$, $n = 20$, $p = 0.230$).

Blue marlin

Three blue marlin ranging from 103.00 to 107.00 inches FL ($\overline{X}$ – 105.7 inches FL) were analyzed for mercury (Table 1). One-hundred percent of the blue marlin samples examined were of legal size (≥ 99 inches FL [federal waters]).[29, 30] Mercury concentrations ranged from 6.200 to 18.500 mg/kg with a mean of 12.900±6.223 and a median of 14.000 mg/kg (Tables 2a).

Little tunny "Bonito"

Twenty-seven little tunny ranging from 18.50 to 29.00 inches TL ($\overline{X}$ – 26.3 inches TL) were analyzed for mercury (Table 1). Currently, there is no length limit for little tunny in Texas or federal waters.[29, 30] Mercury concentrations ranged from 0.132 to 0.818 mg/kg with a mean of 0.499±0.157 and a median of 0.493 mg/kg (Tables 2a). Mercury concentrations in little tunny were positively related to TL ($r^2 = 0.659$, $n = 27$, $p < 0.0005$; Figure 2).

Cobia

Seventeen cobia ranging from 38.00 to 57.00 inches TL ($\overline{X}$ – 40.1 inches TL) were analyzed for mercury (Table 1). One-hundred percent of the cobia samples examined were of legal size (≥ 37 inches TL [Texas waters]; ≥ 33 inches FL [federal waters]).[29, 30] Mercury concentrations ranged from 0.127 to 1.080 mg/kg with a mean of 0.460±0.315 and a median of 0.463 mg/kg (Tables 2a). The SALG risk assessors computed a Pearson product-moment correlation coefficient to assess the relationship between mercury concentration and TL. There was no correlation between the two variables ($r = 0.450$, $n = 17$, $p = 0.070$).

Dolphinfish

Twenty-one dolphinfish ranging from 23.50 to 49.00 inches TL ($\bar{X}$ – 35.4 inches TL) were analyzed for mercury (Table 1). Currently, there is no length limit for dolphinfish in Texas or federal waters.[29, 30] Mercury concentrations ranged from ND to 0.573 mg/kg with a mean of 0.151±0.169 and a median of 0.054 mg/kg (Tables 2a). Mercury concentrations in dolphinfish were positively related to TL (r^2 = 0.876, n = 21, p <0.0005; Figure 3).

Crevalle jack

Seven crevalle jack ranging from 33.00 to 41.50 inches TL ($\bar{X}$ – 38.5 inches TL) were analyzed for mercury (Table 1). Currently, there is no length limit for crevalle jack in Texas or federal waters.[29, 30] Mercury concentrations ranged from 0.857 to 1.480 mg/kg with a mean of 1.005±0.220 and a median of 0.911 mg/kg (Tables 2a).

King mackerel

Seventy-one king mackerel ranging from 31.00 to 49.50 inches TL ($\bar{X}$ – 38.0 inches TL) were analyzed for mercury (Table 1). One-hundred percent of the king mackerel samples examined were of legal size (≥ 27 inches TL [Texas waters]; ≥ 24 inches FL [federal waters]).[29, 30] Mercury concentrations ranged from 0.208 to 1.140 mg/kg with a mean of 0.627±0.196 and a median of 0.619 mg/kg (Tables 2a–2b). The 2011 mean mercury concentrations for king mackerel < 37 inches, 37 to 43 inches, and > 43 inches were 0.524±0.149, 0.670±0.185, and 0.790±0.260 mg/kg, respectively. Mercury concentrations in king mackerel were positively related to TL (r^2 = 0.297, n = 71, p < 0.0005; Figure 4). The SALG risk assessors performed ANOVA to test for differences in king mackerel mercury concentration among the three king mackerel consumption advisory size classes (< 37, 37 to 43, and > 43 inches TL). King mackerel mercury concentrations differed significantly across the three advisory size classes (F [2, 68] = 7.823, p = 0.001; Figure 5). Tukey HSD post-hoc comparisons of the three consumption advisory size classes indicate that the 37 to 43 inches TL size class ($\bar{X}$ = 0.670, 95% CI [0.610, 0.730], p = 0.006) and the > 43 inches TL size class ($\bar{X}$ = 0.790, 95% CI [0.517, 1.063], p = 0.005) had significantly higher mercury concentrations than the < 37 inches TL size class ($\bar{X}$ = 0.524, 95% CI [0.464, 0.584]). Comparisons between the 37 to 43 inches TL size class and the > 43 inches TL size class indicated that the mean mercury concentrations of the two size classes were not statistically different (p = 0.284). Evaluation of mercury concentrations in king mackerel (all size classes) by sampling event indicate that the 1996–1997 and 2011 data do not statistically differ by sampling event (1996–1997, n = 167; 2011, n = 71; t [236] = 1.449, p = 0.149). Mercury concentrations in the combined 1996–1997 and 2011 king mackerel datasets were positively related to TL (r^2 = 0.372, n = 238, p <0.0005; Figure 6). The SALG risk assessors performed ANOVA to test for differences in king mackerel mercury concentration among the three king mackerel consumption advisory size classes (< 37, 37 to 43, and > 43 inches TL) for the combined data from the 1996–1997 and 2011 sampling events. King mackerel mercury concentrations differed significantly across the three advisory size classes (F [2, 235] = 55.094, p < 0.0005; Figure 7). Games-Howell post-hoc comparisons of the three consumption advisory size classes indicate that the 37 to 43 inches TL size class ($\bar{X}$ = 0.808, 95% CI [0.751, 0.864], p

< 0.0005) and the > 43 inches TL size class ($\bar{X}$ = 0.910, 95% CI [0.766, 1.053], $p < 0.0005$) had significantly higher mercury concentrations than the < 37 inches TL size class ($\bar{X}$ = 0.535, 95% CI [0.507, 0.563]). Comparisons between the 37 to 43 inches TL size class and the > 43 inches TL size class indicated that the mean mercury concentrations of the two size classes were not statistically different ($p = 0.360$). The SALG risk assessors also performed a *t*-test to examine differences in mercury concentrations in king mackerel (1996-2011) between two size classes (< 43 and > 43 inches TL). Evaluation of mercury concentrations between the two size classes indicate that king mackerel > 43 in TL contain significantly higher mercury concentrations than king mackerel < 43 inches TL (1996-2011, n = 238; t [236] = -4.733, $p < 0.0005$; Figure 8).

Lane snapper

Four lane snapper ranging from 16.25 to 17.50 inches TL ($\bar{X}$ – 16.9 inches TL) were analyzed for mercury (Table 1). One-hundred percent of the lane snapper samples examined were of legal size (≥ 8 inches TL [Texas waters]; ≥ 8 inches TL [federal waters]).[29, 30] Mercury concentrations ranged from 0.171 to 0.262 mg/kg with a mean of 0.203±0.043 and a median of 0.190 mg/kg (Tables 2a).

Mangrove snapper

Two mangrove snapper ranging from 11.50 to 26.00 inches TL ($\bar{X}$ – 18.8 inches TL) were analyzed for mercury (Table 1). Currently, there is no length limit for mangrove snapper in Texas waters, and 50% of the mangrove snapper samples examined were of legal size for federal waters (≥ 12 inches TL).[29, 30] Mercury concentrations ranged from 0.138 to 0.292 mg/kg with a mean of 0.215±0.109 and a median of 0.215 mg/kg (Tables 2a).

Red snapper

Forty-four red snapper ranging from 16.50 to 29.25 inches TL ($\bar{X}$ – 21.3 inches TL) were analyzed for mercury (Table 1). One-hundred percent of the red snapper samples examined were of legal size (≥ 15 inches TL [Texas waters]; ≥ 16 inches TL [federal waters]).[29, 30] Mercury concentrations ranged from 0.031 to 0.701 mg/kg with a mean of 0.116±0.104 and a median of 0.093 mg/kg (Tables 2a). Mercury concentrations in red snapper were positively related to TL ($r^2 = 0.187$, $n = 44$, $p = 0.003$; Figure 9).

Spanish mackerel

Twenty-one Spanish mackerel ranging from 20.00 to 29.50 inches TL ($\bar{X}$ – 25.4 inches TL) were analyzed for mercury (Table 1). One-hundred percent of the Spanish mackerel samples examined were of legal size (≥ 14 inches TL [Texas waters]; ≥ 12 inches FL [federal waters]).[29, 30] Mercury concentrations ranged from 0.057 to 0.425 mg/kg with a mean of 0.212±0.099 and a median of 0.199 mg/kg (Tables 2a). The SALG risk assessors computed a Pearson product-moment correlation coefficient to assess the relationship between mercury concentration and TL. There was no correlation between the two variables ($r = 0.340$, $n = 21$, $p = 0.131$).

Swordfish

Three swordfish ranging from 51.25 to 79.5 inches FL ($\overline{X}$ – 68.1 inches FL) were analyzed for mercury (Table 1). One-hundred percent of the swordfish samples examined were of legal size (no length limit [Texas waters]; ≥ 47 inches FL [federal waters]).[29, 30] Mercury concentrations ranged from 1.010 to 1.480 mg/kg with a mean of 1.183±0.258 and a median of 1.060 mg/kg (Tables 2a).

Tripletail

Nine tripletail ranging from 17.00 to 23.00 inches TL ($\overline{X}$ – 19.3 inches TL) were analyzed for mercury (Table 1). One-hundred percent of the tripletail samples examined were of legal size (≥ 17 inches TL [Texas waters]; no length limit [federal waters]).[29, 30] Mercury concentrations ranged from ND to 0.056 mg/kg with a mean of 0.026±0.017 and a median of 0.017 mg/kg (Tables 2a).

Wahoo

Nine wahoo ranging from 40.00 to 61.75 inches TL ($\overline{X}$ – 49.5 inches TL) were analyzed for mercury (Table 1). Currently, there is no length limit for wahoo in Texas or federal waters.[29, 30] Mercury concentrations ranged from 0.088 to 2.380 mg/kg with a mean of 0.752±0.805 and a median of 0.381 mg/kg (Tables 2a). Mercury concentrations in wahoo were positively related to TL ($r^2 = 0.962$, $n = 9$, $p < 0.0005$; Figure 10).

Yellowfin tuna

Thirteen yellowfin tuna ranging from 34.75 to 63.00 inches TL ($\overline{X}$ – 46.0 inches TL) were analyzed for mercury (Table 1). One-hundred percent of the yellowfin tuna samples examined were of legal size (no length limit [Texas waters]; ≥ 27 inches FL [federal waters]).[29, 30] Mercury concentrations ranged from 0.080 to 0.929 mg/kg with a mean of 0.242±0.279 and a median of 0.128 mg/kg (Tables 2a). Mercury concentrations in yellowfin tuna were positively related to TL ($r^2 = 0.328$, $n = 13$, $p = 0.041$; Figure 11).

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.[16] 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 endpoints in those who would consume fish from the NWGOM. 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 from the NWGOM

<u>Mercury</u>

Two-hundred eighty-one of 288 fish collected from NWGOM in 2011 contained mercury (Tables 2a–2b). Twenty-five percent of all samples (n = 288) analyzed contained mercury concentrations that equaled or exceeded the HAC_{nonca} for mercury (0.700 mg/kg). Mercury concentrations that equaled or exceeded the HAC_{nonca} for mercury were observed in one or more samples of the following species: Atlantic sharpnose shark, blackfin tuna, blue marlin, little tunny, cobia, crevalle jack, king mackerel, red snapper, swordfish, wahoo, and yellowfin tuna. Mean mercury concentrations for all size classes assayed of Atlantic sharpnose shark, blackfin tuna, blue marlin, crevalle jack, swordfish, and wahoo equaled or exceeded the HAC_{nonca} for mercury.

Significant positive relationships between mercury concentration and TL were observed in many fish from the NWGOM, indicating that mercury concentrations increase as fish grow (Figures 2–10). The six species evaluated (Atlantic sharpnose shark, blackfin tuna, blacktip shark, cobia, crevalle jack, and Spanish mackerel) that did not have significant mercury concentration–TL relationships all exhibited positive relationships between the two variables. The significance of these relationships was likely limited by small sample size and size distribution evaluated for each species. The SALG risk assessors evaluated the significant positive relationships and corresponding regression equations to predict the TL by species at which the mercury concentration equaled or exceeded the HAC_{nonca} for mercury. Dolphinfish and yellowfin tuna mercury–TL regression analyses predicted that mercury concentrations equivalent to the HAC_{nonca} for mercury occurred at larger TLs than represented by the study data. Thus, the SALG risk assessors considered the use of mercury regression equations for dolphinfish and yellowfin tuna inappropriate for recommending size class fish consumption advice. The mercury–TL linear regression equation for little tunny estimated that little tunny > 27 inches TL contain mercury concentrations equivalent to the HAC_{nonca} for mercury (Figure 2). The mercury–TL linear regression equation (1996–1997 and 2011 data; n = 238) for king mackerel predicted that king mackerel > 35 inches TL contain mercury concentrations equivalent to the HAC_{nonca} for mercury (Figure 6). Current king mackerel fish consumption advisory size class mean mercury concentrations indicate that king mackerel 37 to 43 and > 43 inches TL contain mercury concentrations that exceed the HAC_{nonca} for mercury. The mercury–TL linear regression equation for red snapper predicted that up to a reported maximum length of 39 inches TL for this species mercury concentrations equivalent to the HAC_{nonca} for mercury were unattainable (Figure 9). The mercury–TL linear regression equation for wahoo predicted that wahoo > 53 inches TL contain mercury concentrations equivalent to the HAC_{nonca} for mercury (Figure 10).

Meal consumption calculations may be useful for decisions about consumption advice or regulatory actions. The SALG risk assessors calculated the number of eight-ounce meals of fish from the NWGOM that healthy adults could consume without significant risk of adverse systemic effects (Tables 3a–3b). Meal consumption rates were based on the most conservative mercury concentration (i.e. overall mean mercury concentration, predicted mercury concentration by regression equation, or size class mean mercury concentration) by species. The SALG risk assessors estimated that healthy adults could consume 0.7 (eight-ounce) meals per week of Atlantic sharpnose shark, 0.8 (eight-ounce) meals per week of blackfin tuna, 0.9 (eight-ounce) meals per week of little tunny > 27 inches TL, 0.6 (eight-ounce) meals per week of crevalle jack, 0.5 (eight-ounce) meals per week of swordfish, or 0.9 (eight-ounce) meals per week of wahoo containing mercury. The SALG risk assessors also estimated that healthy adults could consume 1.0 (eight-ounce) meals per week of king mackerel < 43 inches TL or 0.7 (eight-ounce) meals per week of king mackerel > 43 inches TL. The SALG risk assessors suggest that fish from the NWGOM contain mercury at concentrations that may pose potential systemic health risks and that people should limit their consumption of fish from the NWGOM. Because the developing nervous system of the human fetus and young children may be especially susceptible to adverse systemic health effects associated with consuming mercury-contaminated fish, the SALG risk assessors recommend more conservative consumption guidance for this sensitive subpopulation.

Notwithstanding, the 2011 NWGOM meal consumption calculations, the SALG risk assessors are also of the opinion that it is important to consider potential exposure when developing fish consumption advisories. Studies have shown that recoveries and yields from whole fish to skin-off fillets range from 17–58%.[31] The SALG risk assessors used an average of 38% recovery and yield from whole fish to skin-off fillets to estimate the number of eight-ounce meals for an average weight fish of each species from the NWGOM in 2011 (Table 4). The recoveries and yields for an average fish of each species from the NWGOM in 2011 ranged from 2.1–328.7 eight-ounce meals. Based on recoveries and yields ($\overline{X}$ – 38%) from whole fish to skin-off fillets for this project, the average NWGOM fish yields 21 pounds of skin-off fillets or approximately 42 eight-ounce meals (Table 4). By comparison, using similar recovery and yield data from Sam Rayburn Reservoir fish (data not shown), the recoveries and yields for Sam Rayburn Reservoir fish ranged from 0.3–15.1 eight-ounce meals. Drawing on the Sam Rayburn Reservoir data to represent the average freshwater fish, the average freshwater fish yields two pounds of skin-off fillets or approximately four eight-ounce meals. This data comparison between fish from the NWGOM and Sam Rayburn Reservoir shows that the average NWGOM fish is much larger than the average freshwater fish and that an average fish from the NWGOM containing a similar mercury concentration to an average freshwater fish is capable of exposing a person to approximately 11 times the amount of mercury. Another way to illustrate the importance of potential exposure from NWGOM fish is to consider the cobia mean mercury concentration (0.460 mg/kg) for this project. Based on a mean mercury concentration of 0.460 mg/kg, a person consuming six eight-ounce meals per month would exceed the MRL. The average cobia for this project yields 9.5 pounds of skin-off fillets, approximately 20 eight-ounce meals, or 4.6 eight-ounce meals per week. Following the cobia example and assuming an average freshwater fish mean mercury concentration of 0.460 mg/kg, an average freshwater fish does not yield the pounds of skin-off fillets necessary to exceed the MRL. Because fish from the NWGOM are of large average size, it is important for high volume fish consumers (persons who eat more than 2 eight-ounce meals per week) to understand that even though an average fish mercury concentration does not exceed the HAC_{nonca} for mercury a person may easily consume enough fish meals to exceed the MRL. For the reasons stated in the above discussion, the SALG risk assessors considered both standard meal consumption calculations and potential exposure scenarios to develop fish consumption advice for fish from the NWGOM.

CONCLUSIONS

The SALG 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 SALG 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 nearshore and offshore waters of Texas (NWGOM). Risk assessors from the SALG conclude from the present characterization of potential adverse health effects from consuming fish from the NWGOM that:

1. Blue marlin and swordfish mean mercury concentrations exceed the DSHS guidelines for protection of human health. Regular or long-term consumption of blue marlin and swordfish may result in adverse systemic health effects. Therefore, regular or long-term consumption of these species of fish from the NWGOM **poses an apparent risk to human health**.

2. Due to the limited geographical sample coverage of the NWGOM, small sample sizes, and lack of larger size classes or older age classes of many fishes assayed in this study and the variability of mercury concentrations observed in fish tissue samples, the SALG risk assessors are unable to characterize adequately health risks associated with consuming mercury-contaminated fish from the NWGOM.

RECOMMENDATIONS

Risk managers at the DSHS have established criteria for issuing fish consumption advisories based on approaches suggested by the EPA.[9, 11, 32] Risk managers at the DSHS may decide to take some action to protect public health if a risk characterization confirms that people can eat four or fewer meals per month (adults: eight-ounces per meal; children: 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).[33] Declarations of prohibited harvesting areas are enforceable under the Texas Health and Safety Code, Subchapter D, parts 436.091 and 436.101.[33] 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, members of the public can make informed decisions about whether and/or how much – contaminated fish or shellfish they wish to consume. The SALG concludes from this risk characterization that consuming blue marlin and swordfish from the NWGOM **poses an apparent hazard to public health.** Therefore, SALG risk assessors recommend that:

1. No one should consume blue marlin from the NWGOM (Table 4).

2. Pregnant women, women who may become pregnant, women who are nursing infants, and children less than 12 years of age or who weigh less than 75 pounds should not consume swordfish from the NWGOM.

3. Women past childbearing age and adult men may consume up to two eight-ounce meals per month of swordfish from the NWGOM.

4. The DSHS SALG should conduct additional monitoring to characterize adequately health risks associated with consuming mercury contaminated pelagic fishes of the NWGOM. The supplementary monitoring should include collection of larger size classes or older age classes of pelagic fishes not represented in the fish samples of this assessment and expansion of the sample collection area to include the entire Texas coast. Additional samples should be collect from the extreme lower and upper Texas coast to enhance coverage. Once the additional sample results are obtained, further advisories may be needed for fish found off the Texas coast.

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 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 512-834-6757.[34] 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.[35] The SALG regularly updates this Web site. The DSHS also provides EPA (http://epa.gov/waterscience/fish/advisories/), the TCEQ (http://www.tceq.state.tx.us), and the 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 downloadable PDF file containing general hunting and fishing regulations booklet available at http://www.tpwd.state.tx.us/publications/nonpwdpubs/media/regulations_summary_2010_2011.pdf .[29] A booklet containing this information is available at all establishments selling Texas fishing licenses.[36] Readers may direct questions about the scientific information or recommendations in this risk characterization to the SALG at 512-834-6757 or may find the information at the SALG's Web site (http://www.dshs.state.tx.us/seafood). Secondarily, one may address inquiries to the Environmental and Injury Epidemiology and Toxicology Unit of DSHS (512-776-7269). 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 Web site 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* (ToxProfiles™). To request a copy of the ToxProfiles™ CD-ROM, PHS, or ToxFAQs™ call 1-800-CDC-INFO (800-232-4636) or email a request to cdcinfo@cdc.gov.

Figure 1. The NWGOM Sample Sites

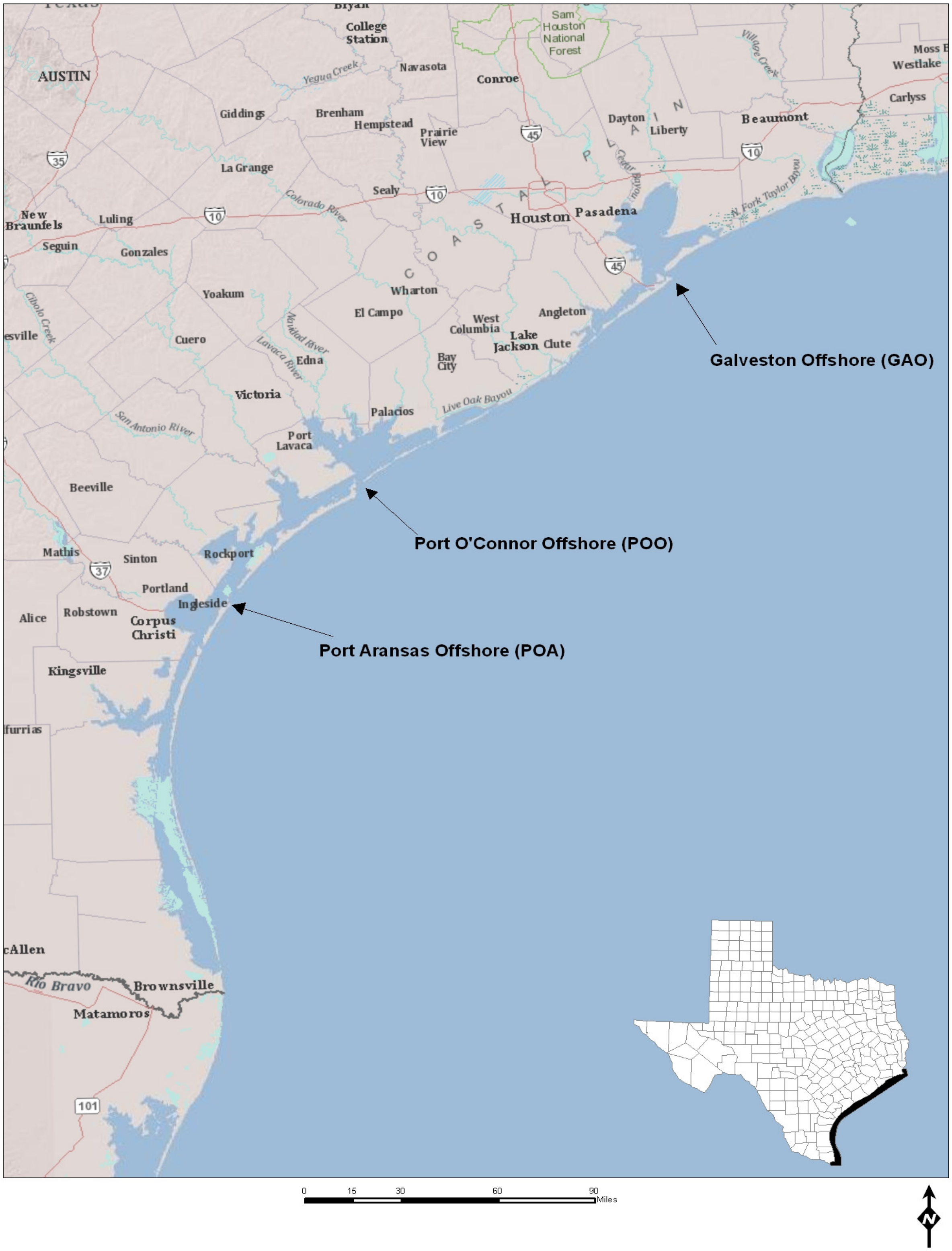


Figure 2. The relationship between mercury concentration and total length for little tunny "bonito" collected from the NWGOM, Texas, 2011.

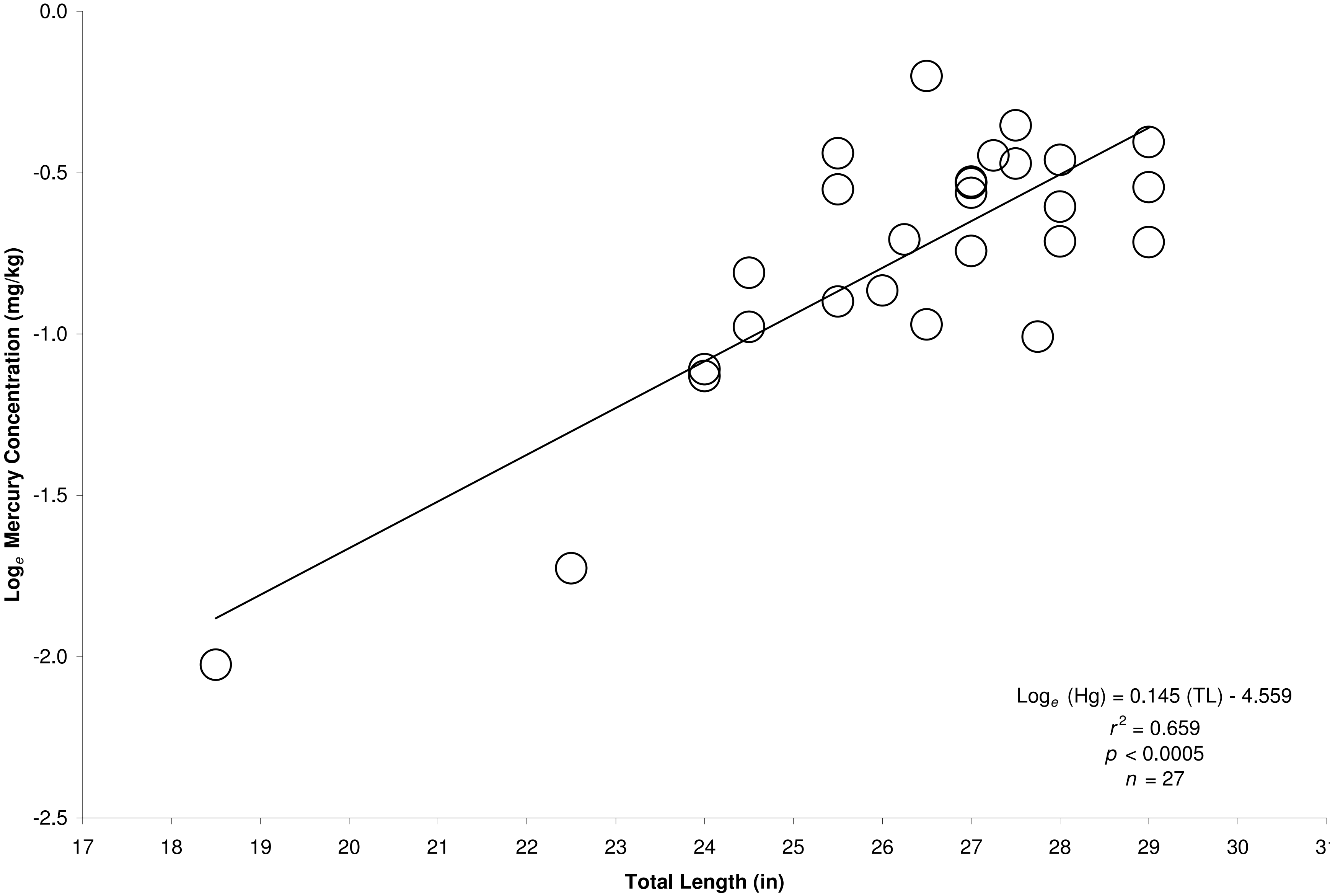


Figure 3. The relationship between mercury concentration and total length for dolphinfish collected from the NWGOM, Texas, 2011.

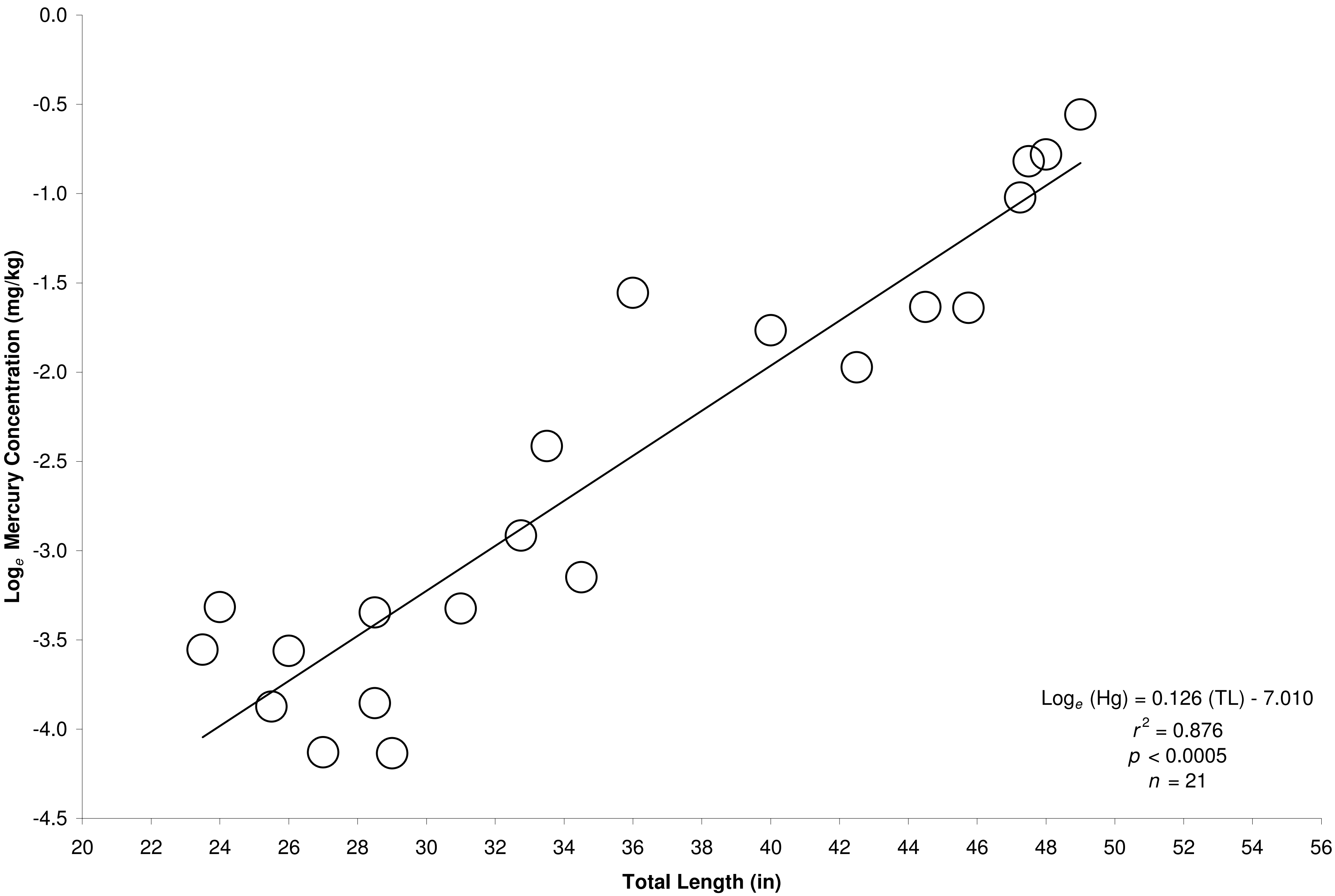


Figure 4. The relationship between mercury concentration and total length for king mackerel collected from the NWGOM, Texas, 2011.

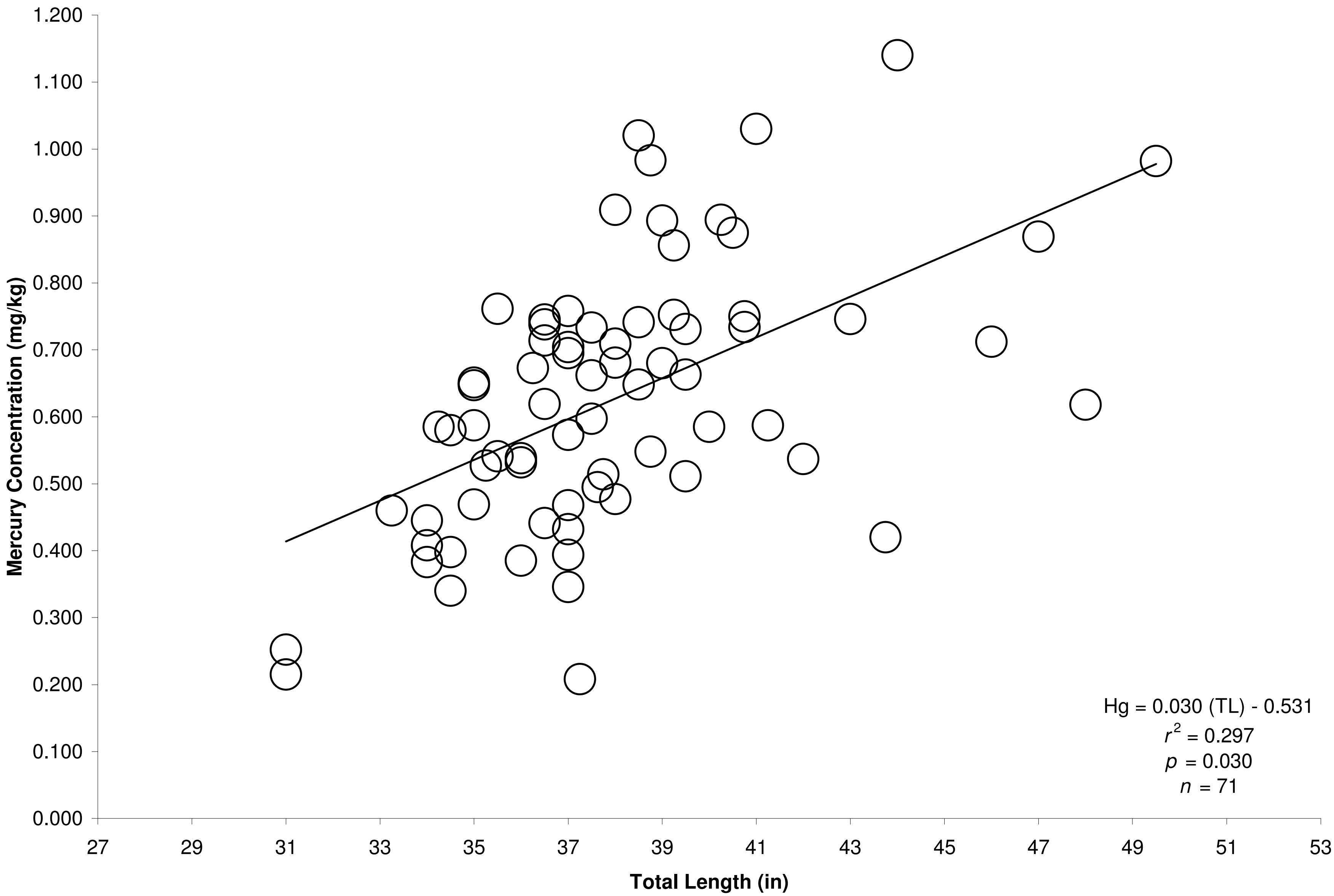


Figure 5. Means plot of mercury (mg/kg, wet wt.) in king mackerel tissue by size class collected from the NWGOM, Texas 2011. The error bars denote the 95% confidence interval of the mean.

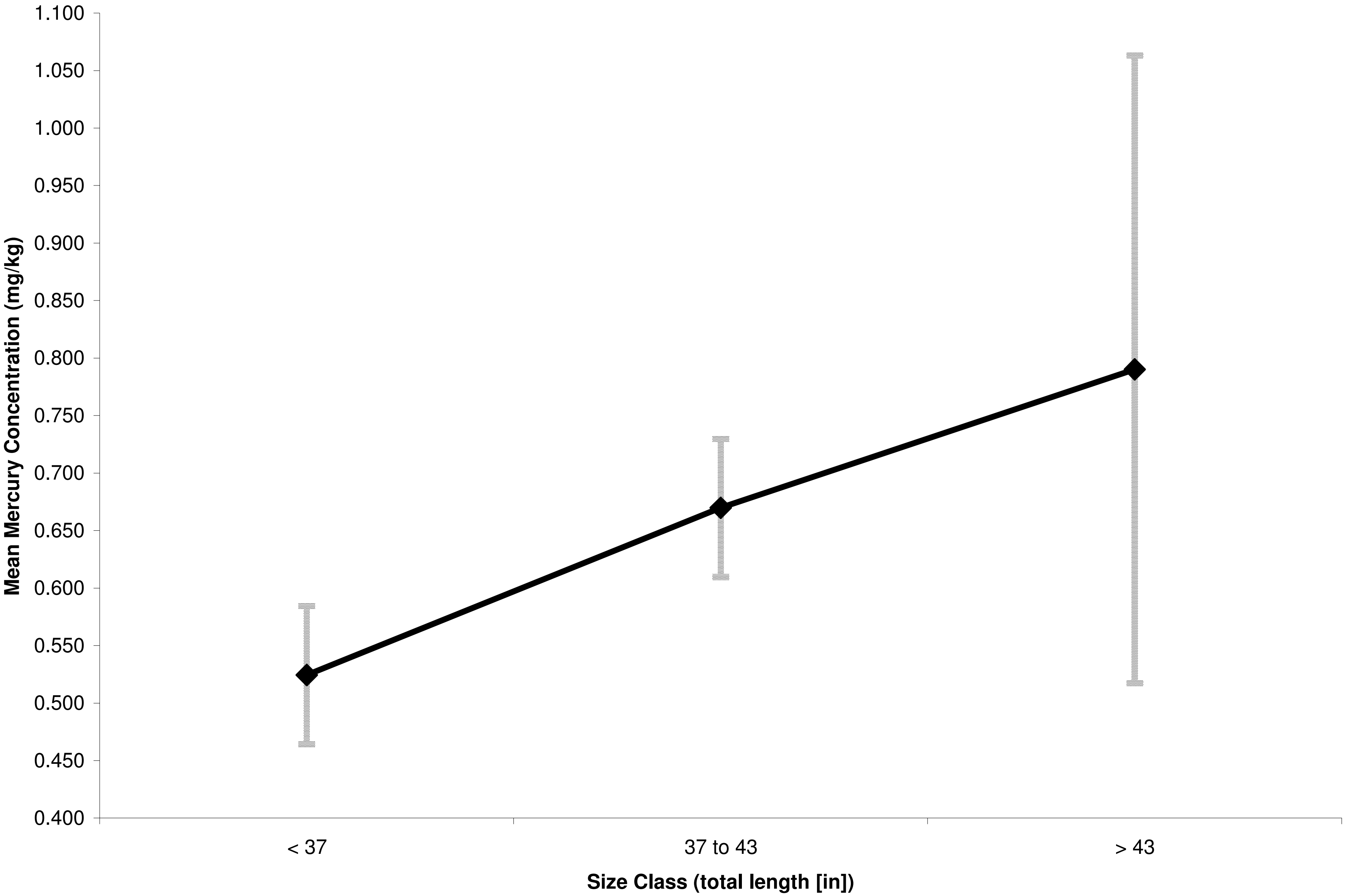


Figure 6. The relationship between mercury concentration and total length for king mackerel collected from the NWGOM, Texas, 1996–2011.

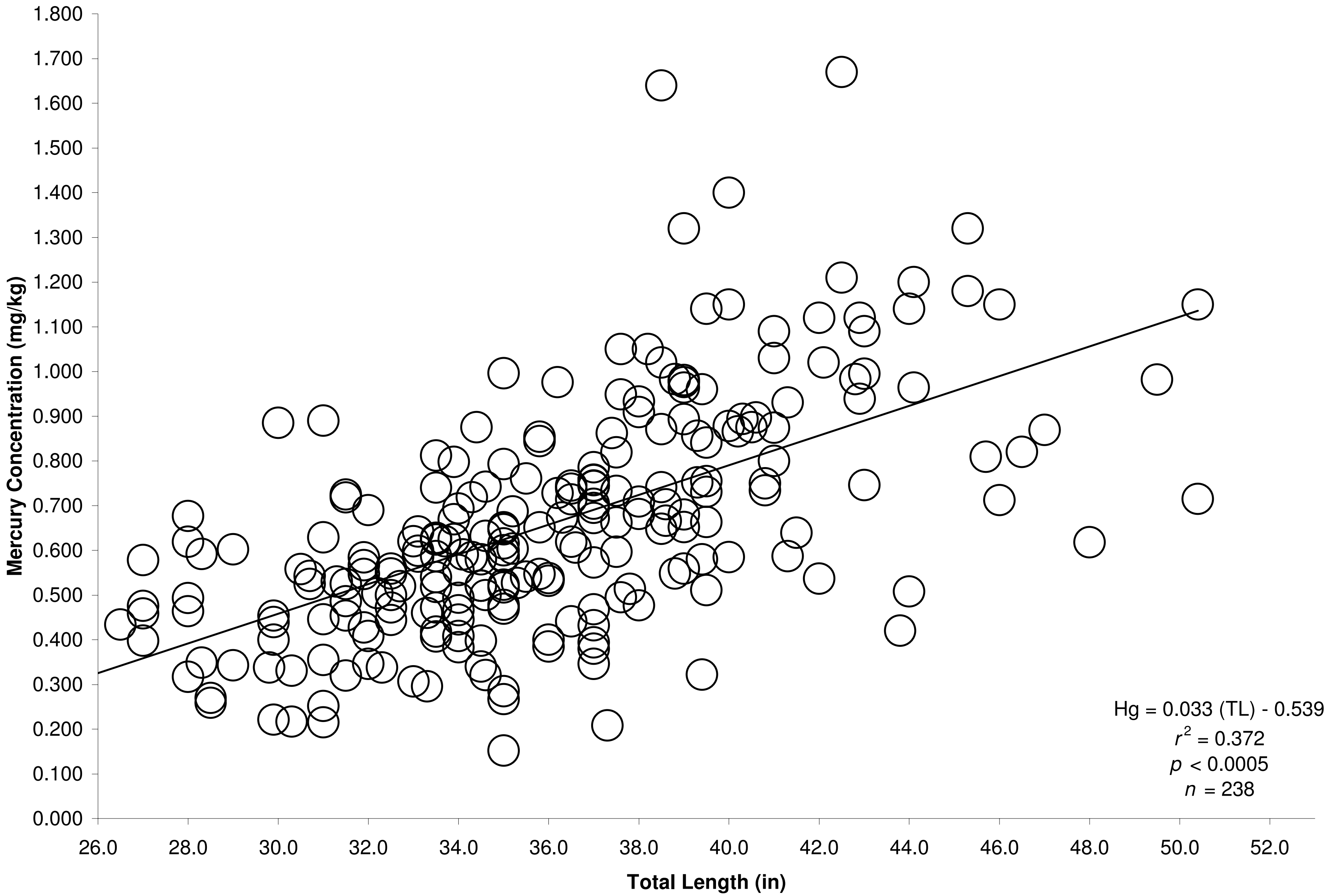


Figure 7. Means plot of mercury (mg/kg, wet wt.) in king mackerel tissue by size class collected from the NWGOM, Texas 1996–2011. The error bars denote the 95% confidence interval of the mean.

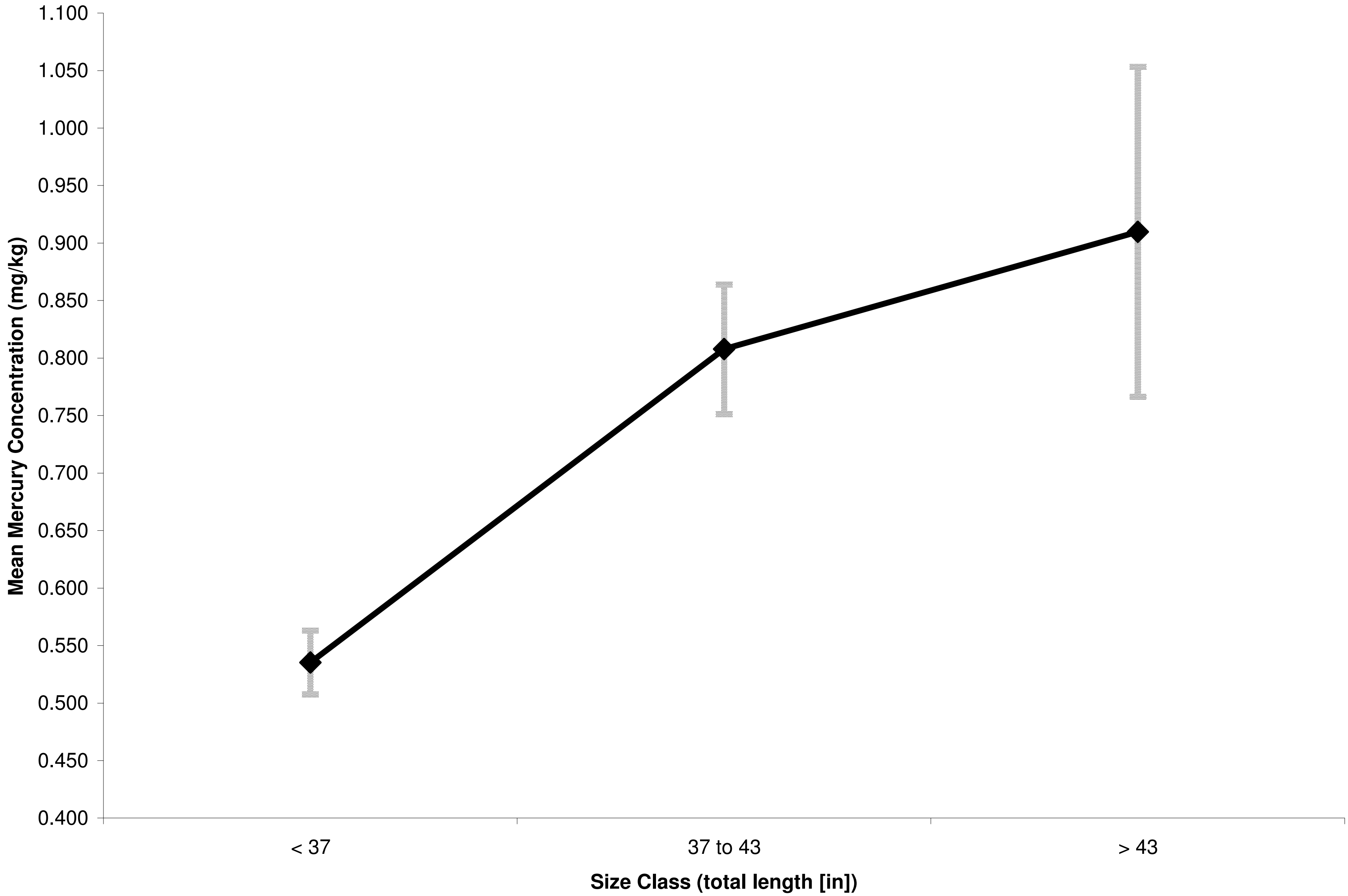


Figure 8. Means plot of mercury (mg/kg, wet wt.) in king mackerel tissue by size class collected from the NWGOM, Texas 1996–2011. The error bars denote the 95% confidence interval of the mean.

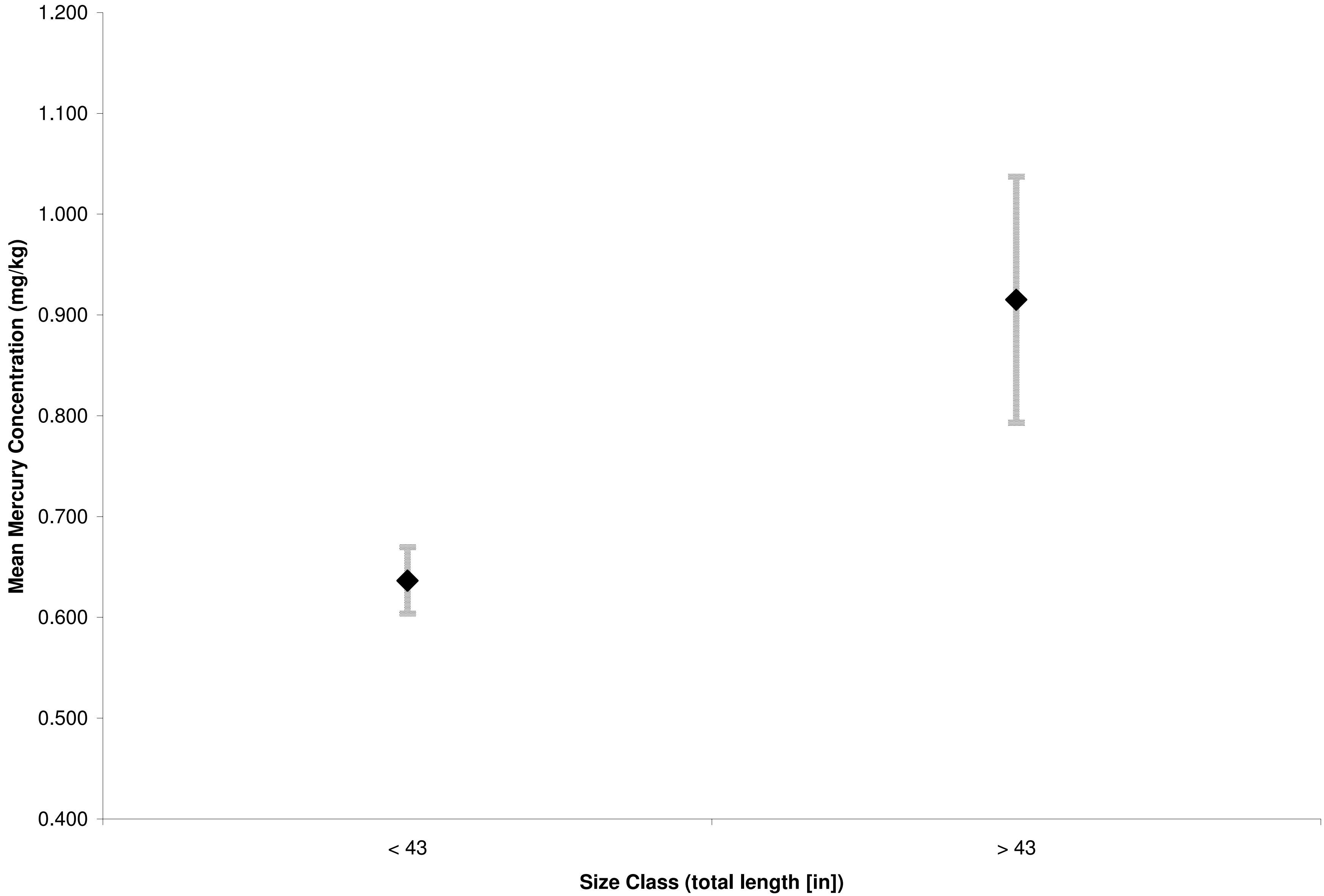


Figure 9. The relationship between mercury concentration and total length for red snapper collected from the NWGOM, Texas, 2011.

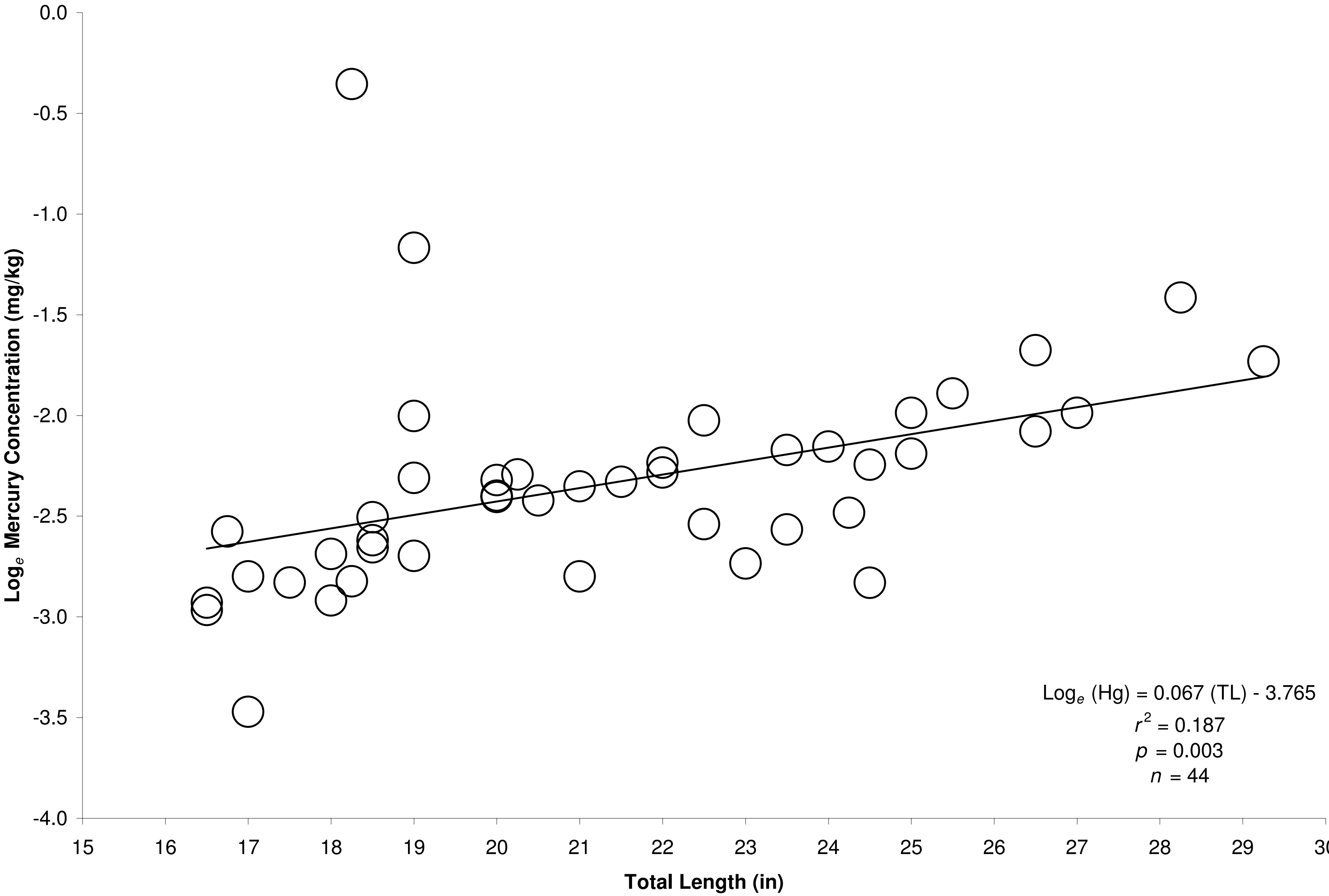


Figure 10. The relationship between mercury concentration and total length for wahoo collected from the NWGOM, Texas, 2011.

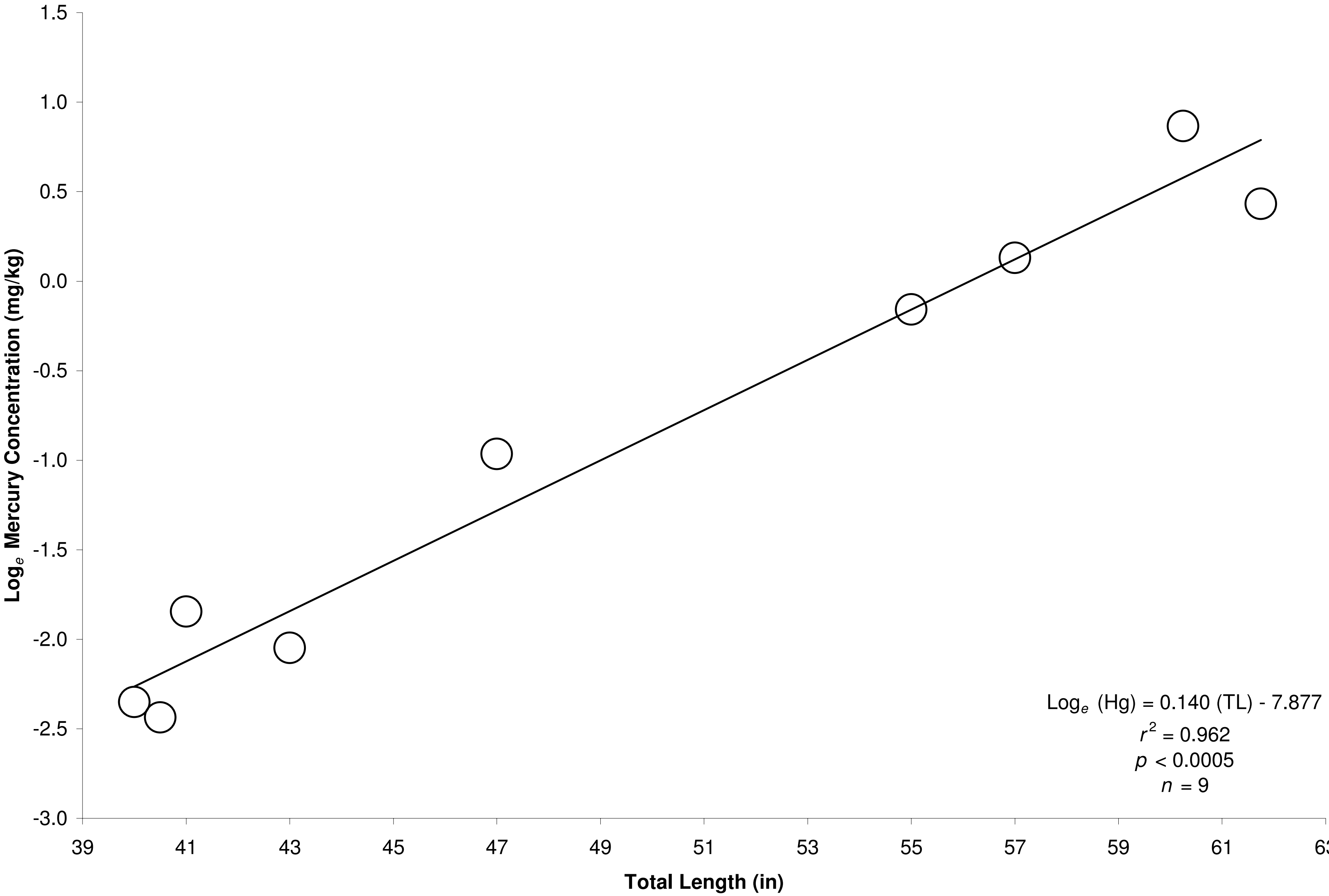
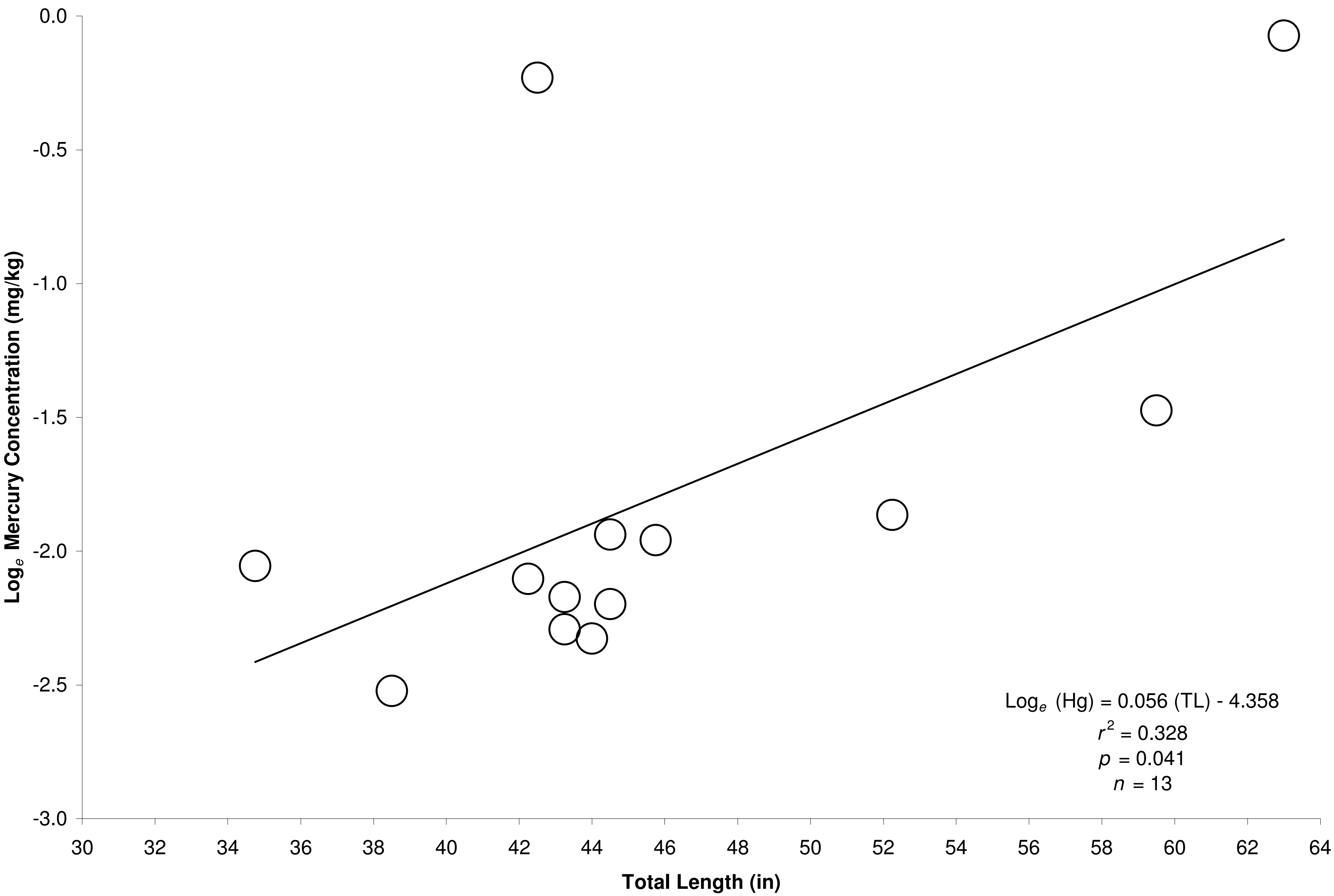


Figure 11. The relationship between mercury concentration and total length for yellowfin tuna collected from the NWGOM, Texas, 2011.



TABLES

Table 1. Fish samples collected from the NWGOM in 2011. Sample number, species, total length, and weight recorded for each sample.

Sample Number	Species	Length (in)	Weight (lb)
Site 1 Galveston Offshore			
GAO37	Atlantic sharpnose shark	36.75	N/A
GAO60	Atlantic sharpnose shark	37.00	7.1
GAO43	Atlantic sharpnose shark	37.25	7.7
GAO10	Atlantic sharpnose shark	38.25	7.6
GAO82	Blacktip shark	28.00	4.1
GAO72	Blacktip shark	29.50	4.4
GAO79	Blacktip shark	29.75	4.7
GAO96	Blacktip shark	39.00	11.0
GAO44	Blacktip shark	39.50	11.2
GAO46	Blacktip shark	40.00	12.3
GAO85	Blacktip shark	40.00	11.8
GAO93	Blacktip shark	40.00	10.3
GAO86	Blacktip shark	40.50	12.5
GAO92	Blacktip shark	40.50	11.0
GAO45	Blacktip shark	41.00	13.6
GAO84	Blacktip shark	41.00	11.9
GAO89	Blacktip shark	41.00	13.5
GAO83	Blacktip shark	41.25	13.3
GAO87	Blacktip shark	41.25	12.0
GAO90	Blacktip shark	41.25	12.3
GAO88	Blacktip shark	42.25	13.7
GAO91	Blacktip shark	43.00	13.5
GAO59	Bonnethead shark	41.00	10.4
GAO19	Cobia	38.00	13.3
GAO36	Cobia	39.00	N/A
GAO38	Cobia	41.00	N/A
GAO11	Cobia	41.50	19.1
GAO18	Cobia	43.50	21.1
GAO40	Cobia	44.00	N/A
GAO39	Cobia	45.50	N/A
GAO15	Dolphinfish	32.75	7.4
GAO12	King mackerel	31.00	4.3
GAO14	King mackerel	33.25	7.1
GAO22	King mackerel	35.00	6.7
GAO56	King mackerel	35.00	5.4
GAO20	King mackerel	36.00	8.0

Table 1 cont. Fish samples collected from the NWGOM in 2011. Sample number, species, total length, and weight recorded for each sample.

Sample Number	Species	Length (in)	Weight (lb)
Site 1 Galveston Offshore			
GAO57	King mackerel	36.25	8.3
GAO21	King mackerel	36.50	8.9
GAO28	King mackerel	37.00	9.3
GAO13	King mackerel	37.50	9.7
GAO35	King mackerel	37.63	N/A
GAO23	King mackerel	38.00	10.1
GAO25	King mackerel	39.00	9.8
GAO26	King mackerel	39.25	11.9
GAO27	King mackerel	39.25	11.6
GAO24	King mackerel	40.00	14.8
GAO55	King mackerel	44.00	11.7
GAO29	King mackerel	48.00	21.5
GAO2	Mangrove snapper	11.50	0.7
GAO1	Mangrove snapper	26.00	7.5
GAO3	Red snapper	19.00	3.5
GAO5	Red snapper	19.00	3.1
GAO8	Red snapper	20.00	3.9
GAO7	Red snapper	20.25	3.8
GAO4	Red snapper	21.00	3.9
GAO6	Red snapper	22.00	5.1
GAO42	Spanish mackerel	20.00	1.5
GAO94	Spanish mackerel	20.00	1.4
GAO58	Spanish mackerel	22.00	1.3
GAO31	Spanish mackerel	24.25	3.0
GAO95	Spanish mackerel	25.00	2.6
GAO52	Spanish mackerel	26.00	2.5
GAO30	Spanish mackerel	26.50	3.8
GAO54	Spanish mackerel	27.00	2.6
GAO53	Spanish mackerel	28.50	N/A
GAO16	Tripletail	17.00	3.4
GAO32	Tripletail	17.50	3.8
GAO61	Tripletail	18.50	4.3
GAO47	Tripletail	19.00	4.7
GAO48	Tripletail	19.50	4.2
GAO49	Tripletail	19.50	4.7
GAO34	Tripletail	20.00	6.5

Table 1 cont. Fish samples collected from the NWGOM in 2011. Sample number, species, total length, and weight recorded for each sample.

Sample Number	Species	Length (in)	Weight (lb)
Site 1 Galveston Offshore			
GAO41	Tripletail	23.00	7.6
Site 2 Port O'Connor Offshore			
POO124	Atlantic sharpnose shark	34.00	5.3
POO126	Atlantic sharpnose shark	34.25	6.4
POO125	Atlantic sharpnose shark	38.75	8.6
POO108	Blackfin tuna	30.00	15.5
POO107	Blackfin tuna	31.00	16.5
POO106	Blackfin tuna	31.50	16.9
POO105	Blackfin tuna	32.50	16.3
POO104	Blackfin tuna	33.00	19.3
POO103	Blackfin tuna	35.75	18.0
POO128	Blacktip shark	50.75	22.6
POO127	Blacktip shark	52.25	24.1
POO112	Little tunny	24.50	6.3
POO118	Little tunny	24.50	6.4
POO111	Little tunny	25.50	8.6
POO115	Little tunny	25.50	8.2
POO122	Little tunny	26.25	7.6
POO114	Little tunny	26.50	9.3
POO117	Little tunny	26.50	8.7
POO119	Little tunny	27.00	7.3
POO120	Little tunny	27.25	8.6
POO113	Little tunny	27.50	10.7
POO116	Little tunny	27.50	10.3
POO123	Little tunny	27.75	8.3
POO110	Little tunny	28.00	10.6
POO121	Little tunny	28.00	7.9
POO81	Cobia	38.00	N/A
POO50	Cobia	38.25	14.6
POO32	Cobia	40.50	18.2
POO109	Cobia	43.50	19.7
POO80	Cobia	44.75	N/A
POO33	Cobia	48.50	26.5
POO95	Dolphinfish	24.00	N/A
POO101	Crevalle jack	33.00	13.0

Table 1 cont. Fish samples collected from the NWGOM in 2011. Sample number, species, total length, and weight recorded for each sample.

Sample Number	Species	Length (in)	Weight (lb)
Site 2 Port O'Connor Offshore			
POO54	Crevalle jack	37.00	17.5
POO102	Crevalle jack	38.75	21.0
POO64	Crevalle jack	39.50	20.2
POO62	Crevalle jack	40.00	22.2
POO63	Crevalle jack	40.00	20.2
POO100	Crevalle jack	41.50	28.0
POO85	King mackerel	34.00	N/A
POO70	King mackerel	34.25	N/A
POO78	King mackerel	34.50	N/A
POO87	King mackerel	34.50	N/A
POO89	King mackerel	34.50	N/A
POO79	King mackerel	35.00	N/A
POO75	King mackerel	35.25	N/A
POO76	King mackerel	35.50	N/A
POO83	King mackerel	35.50	N/A
POO48	King mackerel	36.50	9.9
POO60	King mackerel	36.50	9.3
POO72	King mackerel	36.50	N/A
POO49	King mackerel	37.00	8.6
POO55	King mackerel	37.00	10.7
POO57	King mackerel	37.00	11.1
POO66a	King mackerel	37.00	N/A
POO97	King mackerel	37.00	N/A
POO67a	King mackerel	37.25	N/A
POO59	King mackerel	37.50	10.7
POO56	King mackerel	37.75	11.9
POO71	King mackerel	38.00	N/A
POO47	King mackerel	38.50	10.8
POO68	King mackerel	38.50	N/A
POO69	King mackerel	38.75	N/A
POO84	King mackerel	38.75	N/A
POO65a	King mackerel	39.50	N/A
POO82	King mackerel	39.50	N/A
POO88	King mackerel	40.25	N/A
POO73	King mackerel	40.50	N/A
POO58	King mackerel	40.75	12.2

Table 1 cont. Fish samples collected from the NWGOM in 2011. Sample number, species, total length, and weight recorded for each sample.

Sample Number	Species	Length (in)	Weight (lb)
Site 2 Port O'Connor Offshore			
POO86	King mackerel	40.75	N/A
POO74	King mackerel	41.25	N/A
POO77	King mackerel	43.75	N/A
POO129	King mackerel	46.00	21.8
POO67	Lane snapper	16.25	1.9
POO31	Lane snapper	16.50	2.3
POO66	Lane snapper	17.25	2.1
POO30	Lane snapper	17.50	2.5
POO45	Red snapper	16.75	2.3
POO42	Red snapper	17.00	2.8
POO44	Red snapper	17.50	2.8
POO43	Red snapper	18.00	2.5
POO27	Red snapper	18.25	2.9
POO29	Red snapper	18.25	3.0
POO28	Red snapper	18.50	3.4
POO41	Red snapper	18.50	3.0
POO26	Red snapper	19.00	3.2
POO39	Red snapper	20.00	3.7
POO40	Red snapper	20.00	4.0
POO35	Red snapper	20.50	4.6
POO38	Red snapper	21.50	4.6
POO37	Red snapper	23.00	5.6
POO22	Red snapper	24.00	6.8
POO24	Red snapper	24.25	7.2
POO21	Red snapper	24.50	6.9
POO23	Red snapper	25.00	6.5
POO25	Red snapper	26.50	9.0
POO36	Red snapper	28.25	10.8
POO65	Red snapper	29.25	13.3
POO94	Spanish mackerel	23.00	N/A
POO51	Spanish mackerel	24.25	2.3
POO53	Spanish mackerel	25.00	2.6
POO92	Spanish mackerel	25.00	N/A
POO98	Spanish mackerel	25.00	N/A
POO91	Spanish mackerel	25.25	N/A
POO52	Spanish mackerel	26.25	3.2

Table 1 cont. Fish samples collected from the NWGOM in 2011. Sample number, species, total length, and weight recorded for each sample.

Sample Number	Species	Length (in)	Weight (lb)
Site 2 Port O'Connor Offshore			
POO46	Spanish mackerel	27.00	3.8
POO93	Spanish mackerel	27.25	N/A
POO34	Spanish mackerel	28.25	3.9
POO90	Spanish mackerel	28.50	N/A
POO61	Tripletail	19.75	5.2
Site 3 Port Aransas Offshore			
PAO62	Blackfin tuna	30.00	17.0
PAO68	Little tunny	18.50	2.0
PAO69	Little tunny	22.50	5.0
PAO60	Little tunny	24.00	6.0
PAO65	Little tunny	24.00	7.0
PAO67	Little tunny	25.50	8.0
PAO71	Little tunny	26.00	7.0
PAO61	Little tunny	27.00	9.0
PAO70	Little tunny	27.00	8.0
PAO72	Little tunny	27.00	11.0
PAO64	Little tunny	28.00	9.0
PAO58	Little tunny	29.00	12.0
PAO59	Little tunny	29.00	10.0
PAO66	Little tunny	29.00	10.0
PAO32	Cobia	41.00	19.5
PAO31	Cobia	42.00	16.6
PAO37	Cobia	53.00	40.0
PAO57	Cobia	57.00	65.0
PAO18	Dolphinfish	23.50	3.0
PAO22	Dolphinfish	25.50	3.2
PAO20	Dolphinfish	26.00	4.1
PAO21	Dolphinfish	27.00	4.0
PAO23	Dolphinfish	28.50	4.6
PAO35	Dolphinfish	28.50	4.5
PAO33	Dolphinfish	29.00	4.2
PAO42	Dolphinfish	31.00	4.9
PAO41	Dolphinfish	33.50	6.9
PAO17	Dolphinfish	34.50	7.8
PAO19	Dolphinfish	36.00	7.4
PAO24	King mackerel	31.00	5.6
PAO38	King mackerel	34.00	6.4

Table 1 cont. Fish samples collected from the NWGOM in 2011. Sample number, species, total length, and weight recorded for each sample.

Sample Number	Species	Length (in)	Weight (lb)
Site 3 Port Aransas Offshore			
PAO51	King mackerel	34.00	6.9
PAO43	King mackerel	35.00	8.3
PAO46	King mackerel	36.00	8.4
PAO54	King mackerel	36.00	7.1
PAO49	King mackerel	36.50	9.0
PAO36	King mackerel	37.00	9.1
PAO47	King mackerel	37.00	8.6
PAO56	King mackerel	37.50	10.0
PAO48	King mackerel	38.00	7.4
PAO52	King mackerel	38.00	10.6
PAO55	King mackerel	38.50	11.7
PAO44	King mackerel	39.00	10.9
PAO53	King mackerel	39.50	10.2
PAO34	King mackerel	41.00	19.2
PAO39	King mackerel	42.00	14.5
PAO45	King mackerel	43.00	15.4
PAO29	King mackerel	47.00	24.2
PAO50	King mackerel	49.50	29.3
PAO1	Red snapper	16.50	2.1
PAO2	Red snapper	16.50	2.2
PAO9	Red snapper	17.00	2.4
PAO3	Red snapper	18.00	2.8
PAO10	Red snapper	18.50	3.3
PAO11	Red snapper	19.00	3.5
PAO14	Red snapper	21.00	4.8
PAO4	Red snapper	22.00	5.2
PAO12	Red snapper	22.50	5.4
PAO15	Red snapper	22.50	5.7
PAO7	Red snapper	23.50	5.6
PAO28	Red snapper	23.50	6.5
PAO5	Red snapper	24.50	6.4
PAO6	Red snapper	25.00	6.9
PAO13	Red snapper	25.50	7.3
PAO30	Red snapper	26.50	10.7
PAO8	Red snapper	27.00	9.7
PAO40	Spanish mackerel	29.50	4.4

Table 1 cont. Fish samples collected from the NWGOM in 2011. Sample number, species, total length, and weight recorded for each sample.

Sample Number	Species	Length (in)	Weight (lb)
Site 3 Port Aransas Offshore			
PAO27	Wahoo	40.00	9.9
PAO16	Wahoo	40.50	10.2
PAO26	Wahoo	41.00	13.3
PAO25	Wahoo	43.00	13.3
PAO63	Warsaw grouper	40.00	39.0
Sport-fishing Offshore Tournaments			
POO4	Blackfin tuna	32.50	21.5
PAO80A	Blue Marlin	103.00	430.0
POO68a	Blue Marlin	107.00	447.5
PAO73	Blue Marlin	107.00	419.0
POO10	Dolphinfish	40.00	19.7
POO11	Dolphinfish	42.50	25.2
POO8	Dolphinfish	44.50	32.9
POO17	Dolphinfish	45.75	30.2
POO20	Dolphinfish	47.25	34.5
POO16	Dolphinfish	47.50	38.9
POO15	Dolphinfish	48.00	38.0
POO13	Dolphinfish	49.00	35.0
PAO76	Swordfish	51.25	64.4
PAO75	Swordfish	73.50	203.0
PAO74A	Swordfish	79.50	281.0
POO18	Wahoo	47.00	19.0
PAO79	Wahoo	55.00	32.5
PAO78	Wahoo	57.00	49.7
POO19	Wahoo	60.25	59.9
POO2	Wahoo	61.75	64.5
POO5	Yellowfin tuna	34.75	24.0
POO9	Yellowfin tuna	38.50	38.0
PAO84	Yellowfin tuna	42.25	39.1
POO12	Yellowfin tuna	42.50	42.7
POO1	Yellowfin tuna	43.25	51.3
POO3	Yellowfin tuna	43.25	46.9
PAO82	Yellowfin tuna	44.00	47.8
PAO81	Yellowfin tuna	44.50	49.8
PAO83	Yellowfin tuna	44.50	49.6
POO14	Yellowfin tuna	45.75	53.0
POO7	Yellowfin tuna	52.25	47.1
POO6	Yellowfin tuna	59.50	91.9
PAO77	Yellowfin tuna	63.00	140.5

Table 2a. Mercury (mg/kg) in fish collected from the NWGOM, 2011.				
Species	**# Detected/ # Sampled**	**Mean Concentration ± S.D. (Min-Max)**	**Health Assessment Comparison Value (mg/kg)**	**Basis for Comparison Value**
Atlantic sharpnose shark	7/7	**0.899***±0.533 (0.478-**1.890**)	0.7	ATSDR chronic oral MRL: 0.0003 mg/kg–day
Blackfin tuna	8/8	**0.782**±0.238 (0.409-**1.120**)		
Blacktip shark	20/20	0.180±0.121 (0.053-0.508)		
Blue marlin	3/3	**12.900**±6.223 (**6.200-18.500**)		
Little tunny	27/27	0.499±0.157 (0.132-**0.818**)		
Bonnethead shark	1/1	0.547		
Cobia	17/17	0.460±0.315 (0.127-**1.080**)		
Dolphinfish	20/21	0.151±0.169 (ND-0.573)		
Crevalle jack	7/7	**1.005**±0.220 (**0.857-1.480**)		
King mackerel	71/71	0.627±0.196 (0.208-**1.140**)		
Lane snapper	4/4	0.203±0.043 (0.171-0.262)		
Mangrove snapper	2/2	0.215±0.109 (0.138-0.292)		
Red snapper	44/44	0.116±0.104 (0.031-**0.701**)		
Spanish mackerel	21/21	0.212±0.099 (0.057-0.425)		
Swordfish	3/3	**1.183**±0.258 (**1.010-1.480**)		
Tripletail	3/9	0.026±0.017 (ND-0.056)		
Wahoo	9/9	**0.752**±0.805 (0.088-**2.380**)		
Warsaw grouper	1/1	0.416		
Yellowfin tuna	13/13	0.242±0.279 (0.080-**0.929**)		
All fish combined	281/288	0.543±1.417 (ND-**18.500**)		

[*] *Emboldened numbers denote that mercury concentrations equal and/or exceed the DSHS HAC value for mercury.*

Table 2b. Mercury (mg/kg) in king mackerel by size class collected from the NWGOM, 1996–2011.				
Species	**# Detected/ # Sampled**	**Mean Concentration ± S.D. (Min-Max)**	**Health Assessment Comparison Value (mg/kg)**	**Basis for Comparison Value**
Mercury				
King mackerel < 37”	136/136	0.535±0.164 (0.152-**0.996**)		
King mackerel 37 to 43”	86/86	**0.808**±0.264 (0.208-**1.670**)		
King mackerel < 43”	222/222	0.641±0.164 (0.152-**1.670**)		
King mackerel > 43”	16/16	**0.910**±0.269 (0.420-**1.320**)		

Table 3a. Hazard quotients (HQs) for mercury in fish collected from the NWGOM in 2011. Table 3a also provides suggested weekly eight-ounce meal consumption rates for 70-kg adults.[*]			
Species	**Number (N)**	**Hazard Quotient**	**Meals per Week**
NWGOM All Sites			
Atlantic sharpnose shark	7	**1.28**[†]	**0.7**[‡]
Blackfin tuna	8	**1.12**	**0.8**
Blacktip shark	20	0.26	3.6
Blue marlin	3	**18.43**	**0.1**
Little tunny	27	0.71	1.3
Bonnethead shark	1	0.78	1.2
Cobia	17	0.66	1.4
Crevalle jack	7	**1.44**	**0.6**
Dolphinfish	21	0.22	4.3
King mackerel	71	0.90	1.0
Lane snapper	4	0.29	3.2
Mangrove snapper	2	0.31	3.0
Red snapper	44	0.17	5.6
Spanish mackerel	21	0.30	3.1
Swordfish	3	**1.69**	**0.5**
Tripletail	9	0.04	unrestricted[§]
Wahoo	9	**1.07**	**0.9**
Warsaw grouper	1	0.59	1.6
Yellowfin tuna	13	0.35	2.7
All fish combined	288	0.78	1.2

[*] *DSHS assumes that children under 12 years of age and/or those that weigh less than 35 kg eat four-ounce meals.*
[†] *Emboldened numbers denote that the HQ for mercury is ≥ 1.0.*
[‡] *Emboldened numbers denote that the calculated allowable meals for an adult are ≤ one meal per week.*
[§] *The term, unrestricted, denotes that the allowable eight-ounce meals per week are > 21.0.*

Table 3b. Hazard quotients (HQs) for mercury in king mackerel by size class collected from the NWGOM in 2011. Table 3b also provides suggested weekly eight-ounce meal consumption rates for 70-kg adults.*

Species	Number (N)	Hazard Quotient	Meals per Week
NWGOM All Sites			
King mackerel < 37”	136	0.76	1.2
King mackerel 37 to 43”	86	**1.15**	**0.8**
King mackerel < 43”	222	**0.92**	**1.0**
King mackerel > 43”	16	**1.30**	**0.7**

* *DSHS assumes that children under 12 years of age and/or those that weigh less than 35 kg eat four-ounce meals.*

Table 4. The number of eight-ounce meals assuming 38% yield from whole fish to skin-off fillets for an average weight fish of each species from the NWGOM.

Species	Number of Eight-Ounce Meals
Atlantic sharpnose	5.4
Blackfin tuna	13.4
Blacktip shark	9.2
Blue marlin	328.7
Cobia	18.9
Crevalle, jack	15.4
Dolphinfish	9.9
King mackerel	8.0
Little tunny	6.3
Red snapper	3.8
Spanish mackerel	2.1
Swordfish	139.1
Tripletail	3.7
Wahoo	23.0
Yellowfin tuna	42.2
NWGOM fish average	42.0

Table 4. Recommended fish consumption advice by species for the NWGOM .

Contaminant of Concern	Species	Women of Childbearing Age and Children < 12	Women Past Childbearing Age and Adult Men
Mercury	Blue marlin	**DO NOT EAT**	**DO NOT EAT**
	Swordfish	**DO NOT EAT**	2 meals/month

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