CHAPTER NINE

Public Health

Seafood (from Galveston Bay) is generally safe to eat, with the caveat that higher levels of contaminants in the Upper Bay can pose some risk to individual consumers, depending on the frequency and amount of seafood consumed and the biological characteristics of the consumer doing the eating.

–Frank Shipley, *Knowing the State of the Bay: The Need for a Continuing Process*, 1993

Is it safe to swim in Galveston Bay? Can I eat the seafood? To citizens of Texas and the Galveston Bay region, these are compelling questions. News accounts of bay-related health threats get high attention from both the public and the media. For example, dioxin contamination in the upper bay system has led to specific recommendations by the Texas Department of Health to avoid certain seafoods taken from that limited area. Similarly, the Texas Department of Health advises against consumption of any fish from the bay's Clear Creek tributary, due to the discovery (near the Brio Superfund Site) of two suspected cancer-causing chemicals, and a third tied to nervous disorders. And, about half the bay remains permanently or provisionally closed to shellfish harvesting due to potential risk from pathogenic bacteria.

How do conditions in Galveston Bay affect public health? In this chapter, this topic is addressed under three headings: 1) the human health aspects of pathogens (disease-causing microbes), including shellfish closures and the safety of contact recreation (swimming, wade-fishing, jet skiing, etc.); 2) concentrations of toxic chemicals in fish and shellfish from the bay; and 3) the potential risks involved in consuming the bay's seafood, including discussion of the limitations inherent in determining risk.

Two studies provide the main background for this characterization. Jensen (1992) reviewed the current status of regulations for shellfish harvesting areas, shellfish bed closures, sources of bacterial contamination, and the incidence of known pathogenic organisms in the bay. Brooks et al. (1992) reviewed existing data regarding toxic chemicals in selected Galveston Bay organisms and, based on new field samples of fish and shellfish, performed an assessment of chemical risk associated with consumption of Galveston Bay seafood.

PATHOGENS

One important health concern related to human use of Galveston Bay arises from the potential presence of human pathogens in bay waters. Exposure to these pathogens could occur through contact and non-contact recreation or through the consumption of molluscan shellfish, primarily oysters. History provides valid reasons for concern about such menaces as infectious hepatitis, dysentary, ***Vibrio*** infections and cholera. Thanks to scientific understanding and effective regulation by public health agencies, outbreaks related to environmental conditions are now rare. However, occasional instances still occur, reminding us that the *sources* for contamination still exist.

In general oyster consumption, in the absence of a regulatory program, would represent a higher risk than contact recreation due to the fact that oysters naturally filter microbes from the water in feeding, and because they are commonly consumed raw.

Indicator Organisms

Ideally, pathogens should be measured directly in water or seafood organisms. However, this is often not practical owing to the difficulty (and expense) of routinely identifying and enumerating the many different kinds of human pathogens. Instead, *indicator organisms* have been used for regulatory purposes, especially for recreational and shellfish growing waters. Indicator organisms suggest but do not confirm the presence of actual pathogens.

Fecal Coliform Bacteria as Indicator Organisms

A number of possible indicators of human pathogens in water are available, including: fecal coliform bacteria, total coliform bacteria, *E. coli* (a particular bacteria species), fecal streptococcus, and **enterococcus**. The *Texas Surface Water Quality Standards* (Texas Water Commission, 1991), the Texas Natural Resource Conservation Commission water quality monitoring program, and the Texas Department of Health Shellfish Sanitation Program currently use fecal coliform bacteria as the indicator, but have used total coliform in the past. For water testing purposes, fecal coliform bacteria are defined as those coliforms which ferment lactose with gas and acid formation at an elevated temperature of 44.5 °C. Total coliform bacteria, on the other hand, comprise aerobic and facultative anaerobic and other bacteria that respond at 35 °C.

Fecal coliform bacteria naturally occur in the intestines of mammals and birds, their fecal material containing some one million organisms per gram. Each human produces from 100 to 400 billion coliform organisms per day. Since the primary public health concern in the past has been diseases caused by improper treatment and disposal of human wastes, the absence of coliform organisms indicates that a sample is likely free of disease-producing organisms. Conversely, the presence of fecal coliforms indicates contamination that could (but may not) involve more serious pathogens. The use of fecal coliform bacteria as an indicator in drinking and recreational waters has nearly a century of successful application in protecting public health, including about 50 years use in shellfish regulation.

Problems with the use of Fecal Coliforms as Indicators

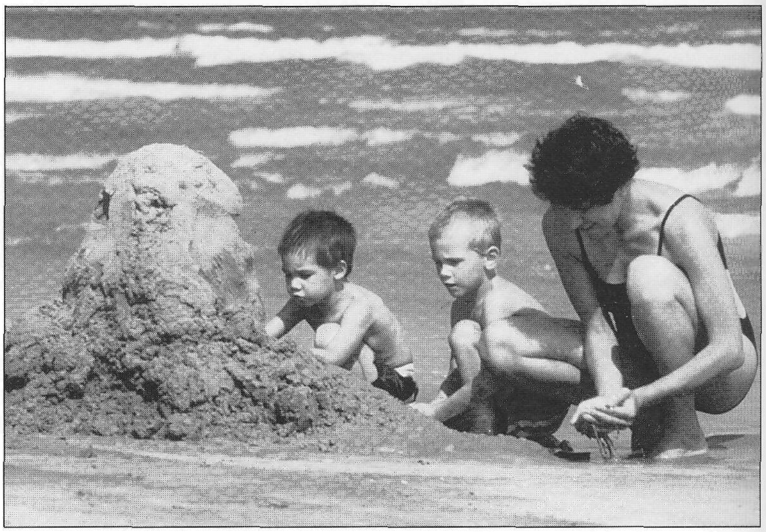
The use of fecal coliforms as an indicator has its limitations. There are some bacterial pathogens which are unrelated to human wastes and therefore not detected in the routine tests (*Vibrio vulnificus* is an example discussed in this chapter). Conversely, many *non-fecal* coliforms common in soil and on the surface of plants cannot be distinguished from fecal coliforms by the tests commonly used. Positive fecal coliform test results have been found for numerous food processing wastes and fish growing ponds, all with no mammalian waste sources. Elevated levels are also found in runoff from agricultural fields with very limited mammalian and avian populations. Thus, elevated concentrations of organic materials from a wide range of sources can support bacterial populations, and the total and fecal coliform tests need to be interpreted with caution.

The fecal coliform test has generally supplanted the total coliform test since the 1970s, in spite of the "false positive" problems resulting from organisms which are not of enteric origin. Studies on contact recreation conducted by the Environmental Protection Agency found that positive fecal coliform tests were not well-correlated with the concentration of actual pathogens.

Sources of Indicator Bacteria

Recent studies suggest that the primary and overwhelming source of fecal coliform bacteria to Galveston Bay is runoff from upland areas, with urbanized areas being one of the major components (see Chapter Six). Part of the reason fecal coliform levels are high in urbanized areas is the contribution from sewer leaks and overflows. However, urban area runoff (even when the collection systems are not leaking) generally has high fecal coliform levels, and runoff occurs in much greater volumes than sewage sources.

Neither septic systems along the bay's shoreline nor permitted point source discharges are major contributors of fecal coliform bacteria to the bay as a whole (Jensen, 1992). Flow from shoreline septic systems is small–each tank can be conservatively expected to release 150 gal/day with a fecal coliform count of 2 x 10^6 colony per 100 mL, not enough to provide a substantial combined load to the bay. For point sources, disinfection required under permit regulations is generally effective. The only time that point sources become a significant portion of the flow to Galveston Bay is during dry weather, at which time fecal coliform levels are at their lowest due to the lack of runoff.



Source: Galveston Bay National Estuary Program

Is the water safe for swimming? The safety of contact recreation, like enjoyment of the Gulf Beach shown here, depends upon bacteria concentrations. Bacteria in some western bay tributaries such as Clear Creek and Dickinson Bayou can exceed safe levels, but these areas are nevertheless popular for water skiing, jet skiing, and other watersports.

Locally, however, septic systems and permitted discharges can both be important contributors of bacteria. This is especially true for enclosed tributaries, as pointed out below in the discussion of water conditions in the bay which affect human activities. Runoff from totally undeveloped land also tends to be high in fecal coliform bacteria (Texas Department of Health et al., 1990), with low incidence of pathogenic organisms.

Contact Recreation

Although swimming beaches are not widespread along the bay's shoreline, considerable contact recreation occurs in various portions of the Galveston Bay system. Clear Lake is known for jet skiing and water skiing; Mud Lake for sail-boarding; Taylor Lake for water skiing, and much of the lower bay shoreline offers good wade-fishing. This contact recreation is not currently routinely regulated. The Texas Department of Health does not have a program for regulating contact recreation, nor does it have a public education program regarding contact recreation.

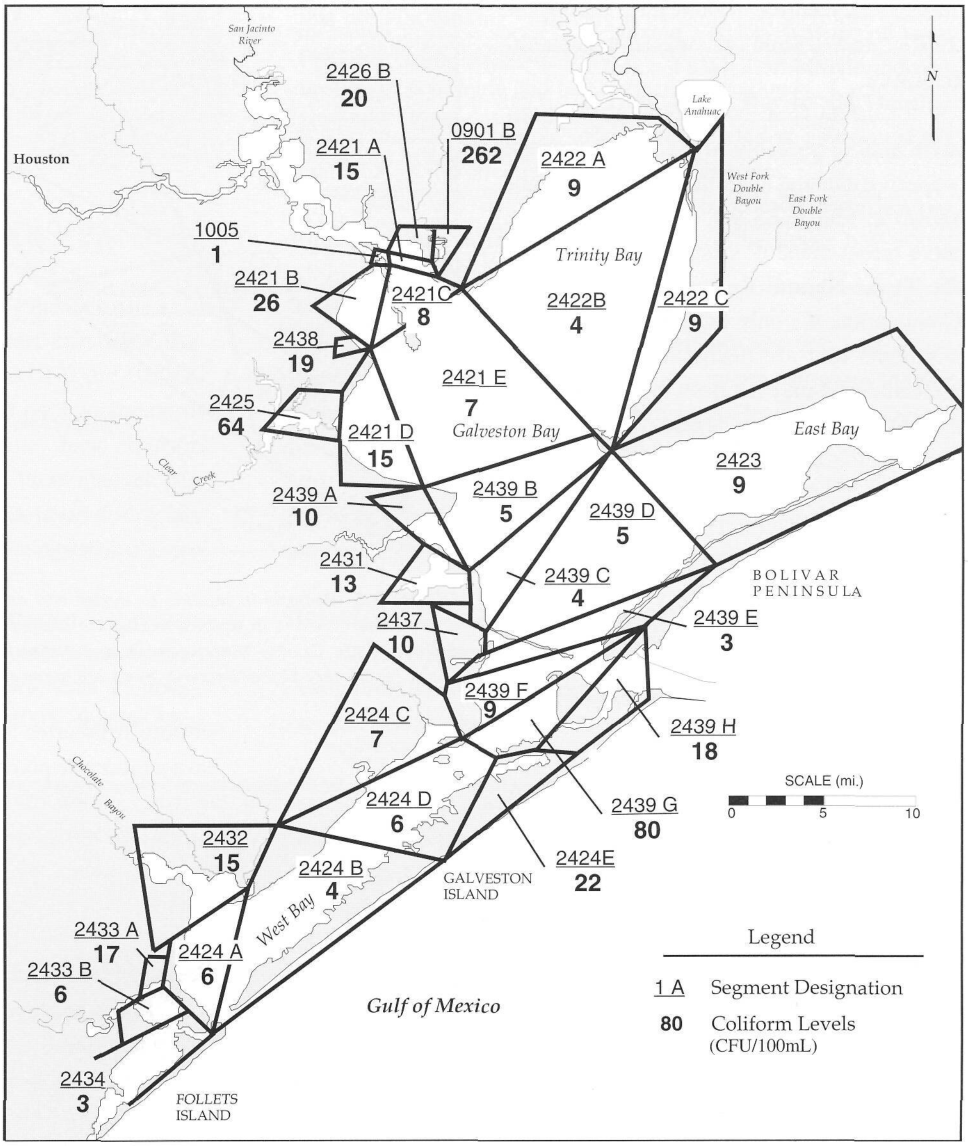
The Texas Natural Resources Conservation Commission indirectly addresses contact recreation by establishing "designated uses" and related water quality standards (Texas Water Commission, 1991). This program is aimed at water quality management rather than determining any risks to the public engaged in contact recreation. These standards and the Texas Natural Resource Conservation Commission water quality monitoring data can be used to evaluate whether the designated use is being met, and more specifically, whether water quality generally supports the use of bay waters for contact recreation (see box page 195). The criterion for this designation is the fecal coliform test, as determined by the membrane filter method.

How frequently is the Texas Natural Resource Conservation Commission criterion for contact recreation violated? Data compilations were conducted during two Galveston Bay National Estuary Program projects carried out by the University of Texas (Ward and Armstrong, 1992) and by Espey, Huston, and Associates (Jensen, 1992). Findings indicated that–over the long term–all *open bay areas* of the system met the Texas water quality criterion for contact recreation of 200 **colony forming units** (CFU) per 100 mL (FIGURE 9.1). This comparison was developed by calculating the long-term geometric mean of the available fecal coliform data from the late 1960s to 1991 and comparing this geometric mean to the 200 CFU per 100 mL standard. (Note that this method does not meet the sampling criteria specified in the *Standards* themselves – in general data were too sparce to conduct such a study.) Over the short term, of course, bacteria levels at any time and place would be determined by the actual events related to contamination.

A second analysis of the same bacteria data is presented in FIGURE 9.2, showing the percentage of samples that exceed the 200 CFU per 100 mL standard for contact recreation and the 14 CFU per 100 mL standard for "oyster waters." None of the segments shown in FIGURE 9.2 have more than a 50 percent exceedence rate relative to the 200 CFU per 100 mL standard for contact recreation. In general, the open waters of Galveston Bay appear to be safe for contact recreation.

Problem Areas for Contact Recreation

In bay tributaries with poor circulation and more numerous surrounding sources of contamination, the picture is somewhat different. The following urbanized bayous on the western side of the bay currently have a Texas Natural Resource Conservation Commission contact recreation designation, but were found by



Source: Jensen, 1992

FIGURE 9.1. *Long-term mean fecal coliform bacteria concentrations in Galveston Bay generally show that open-water portions of the bay meet contact recreation standards specified in the Texas Surface Water Quality Standards. Problem areas occur in urbanized tributaries, particularly on the western shoreline. Depiction of these long-term values tends to mask temporary exceedences of bacterial standards, as would occur in some locations following runoff.*

Jensen (1992) to exceed the contact recreation criterion for a 30-year analysis: Cedar Bayou Tidal, Buffalo Bayou Tidal, Clear Creek Tidal, Dickinson Bayou Tidal, Bastrop Bayou Tidal, Sims Bayou, Brays Bayou and Hunting Bayou.

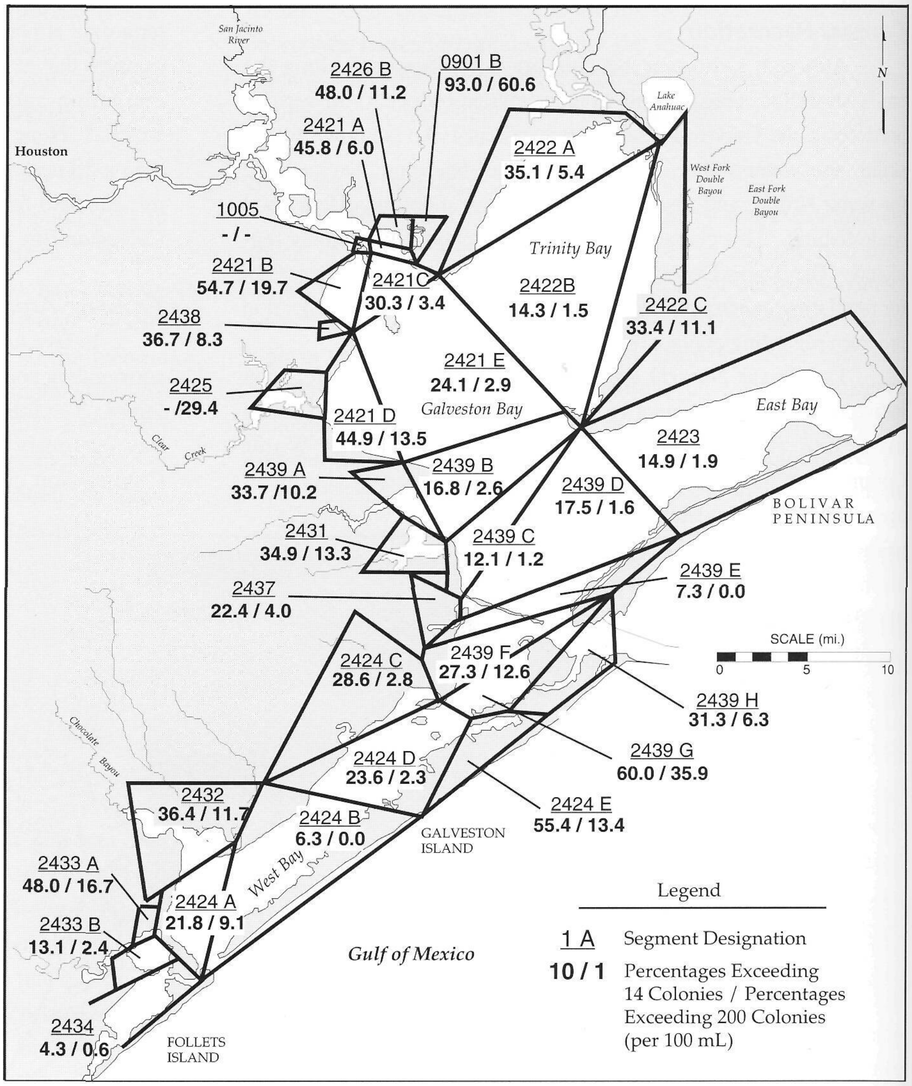
However, this 30-year analysis has limited use in predicting current bacteria levels. Data used to calculate the geometric mean included samples from the 1960s when severe wastewater treatment plant overloading and gross pollution of the areas' urbanized streams was occurring. As shown by Ward and Armstrong (1992) the fecal coliform concentrations in the western tributaries that Jensen analyzed fell significantly during the 1970s and 1980s as waste treatment improved.

Current fecal coliform concentrations are therefore probably lower in many of the western tributaries than the long-term means shown in FIGURES 9.1 and 9.2. Based on more recent monthly sampling performed by the Texas Natural Resource Conservation Commission, the only tidally-affected stream segments that are designated for contact recreation and may not meet the 200 CFU per 100 mL standard are (Galveston Bay National Estuary Program, 1993):

Buffalo Bayou Tidal (mean of 8,309 CFU per 100 mL),

Clear Creek Tidal (mean of 334 CFU per 100 mL)

Dickinson Bayou Tidal (mean of 445 CFU per 100 mL)



Source: Jensen, 1992

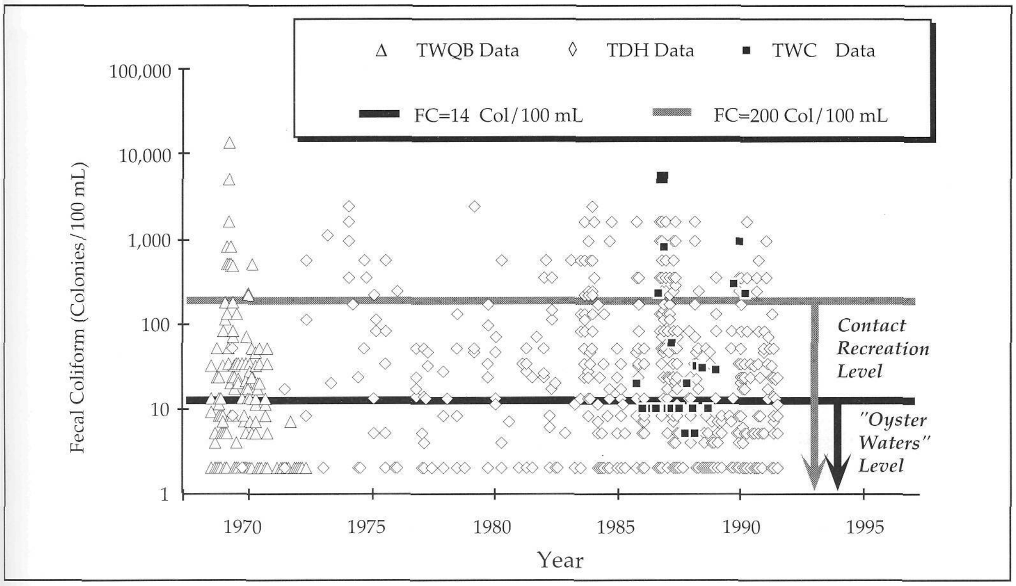
FIGURE 9.2. *Bacteria in relation to oyster and contact recreation criteria. Long-term mean fecal coliform bacteria levels in Galveston Bay are expressed as a percentage exceeding the criteria in* Texas surface Water Quality Standards. *Data indicate few violations in open-water areas on a long-term basis. Temporary higher bacteria levels are generally associated with runoff to the bay.*

The overall trend in fecal coliform bacterial concentrations appears to be one of decline, with much data scatter at specific locations. Ward and Armstrong (1992) showed a generally decreasing trend in fecal coliform concentrations in most of the bay over the past 20 years. Jensen (1992) indicated that despite major population increases in the urban areas of the watershed since the 1960s, no evidence of a systematic increase in fecal coliforms could be identified in Galveston Bay. FIGURE 9.3 illustrates this point with the available fecal coliform data for Galveston Bay near Seabrook for the period 1965 - 1992. Total coliform data collected in the same area from 1958 - 1980 show a similar high variability that obscures possible long-term trends. The improvements in sewage treatment over the last several decades have likely helped to reduce overall bacterial contamination.

In summary, potential contact recreation risks exist in the western tributaries (some with septic tank problems) which still have a moderate potential to infect humans engaged in water-related activities. Some of the more popular areas for contact recreation in the bay are not currently sampled for fecal coliform bacteria. The open bay waters, by contrast, generally have low bacterial concentrations.

Non-Contact Recreation

Non-contact recreational activities in Galveston Bay include such water-based activities as power-boating and sailing. While contact with the water during these activities is limited, some contact may occur. The Texas Department of Health does not have a program regulating non-contact recreation. However, the water quality standards set by the Texas Natural Resource Conservation Commission recognize the limited human health risks associated with non-contact recreation. One designated use under the water quality standards is "non-contact recreation" and, as for contact



Source: Jensen, 1992

FIGURE 9.3. Fecal coliform bacteria concentrations in Galveston Bay off Seabrook exhibit large variability, caused mainly by rainfall runoff conditions. Trends are not generally discernible for localized areas of the bay like this, but taken over larger areas, coliform bacteria have shown a probable decline. Criteria for "oyster waters" (14 CFU per 100 mL) and for contact recreation (200 CFU per 100 mL) are shown.

recreation, the criterion for this designation is the fecal coliform test as determined by the membrane filtration test.

The non-contact designation allows ten times greater fecal coliform bacterial concentration than the contact criterion. It is defined as a fecal coliform count less than 2000 CFU per 100 mL of water expressed as a geometric mean based on a minimum of five samples collected over a 30-day period; *and* fecal coliform content exceeding 4000 CFU per 100 mL in no more than ten percent of all samples based on at least five samples taken during any 30-day period; *and* if ten or fewer samples are analyzed, only one sample can exceed 4000 CFU per 100 mL.

All segments designated for contact recreation and oysters waters are also expected to meet the 2000 CFU per mL non-contact recreation criterion. In addition, the following segments are designated for non-contact recreation use: Segment 1005-Houston Ship Channel/San Jacinto River; Segment 2437-Texas City Ship Channel; and Segment 2438-Barbours Cut. The 2000 CFU per 100 mL criterion is also applied to Segment 1006-Houston Ship Channel, and Segment 1007-Houston Ship Channel/Buffalo Bayou.

Jensen (1992) found that the following segments violated the 2000 CFU per 100mL non-contact criterion: Segment 1005 -Houston Ship Channel/San Jacinto River; Segment 1007-Houston Ship Channel/Buffalo Bayou; Segment 1013-Buffalo Bayou Tidal; and Segment 1014-Buffalo Bayou Above Tidal. In addition, Sims Bayou, Brays Bayou and Hunting Bayou exceeded the non-contact recreation criterion. These are all urbanized tributaries with limited circulation surrounded by potential sources of bacteria.

Shellfish Bed Closures

The consumption of oysters, especially raw, can pose a significant health risk, since oysters can concentrate pathogens in their gut as they feed. The Texas Department of Health has a program that restricts the harvesting of oysters to protect the public from this health risk (see box on page 196), while the Texas Natural Resource Conservation Commission carries out a program to maintain water quality in areas designated for shellfish harvest.

Use of Indicator Tests

Fecal coliform bacteria are used in the Texas Department of Health program as an indicator, and the test procedure has evolved over the years. Prior to the late-1970s, the Texas Department of

TEXAS NATURAL RESOURCE CONSERVATION COMMISSION CRITERIA FOR CONTACT RECREATION

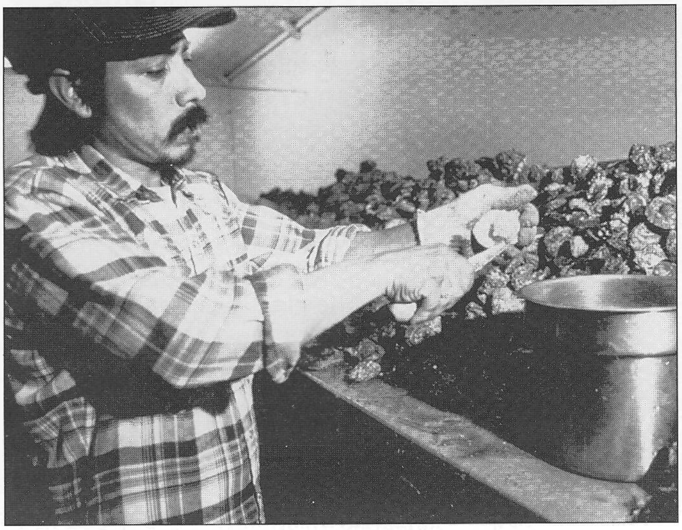
The following criteria are utilized by the Texas Natural Resource Conservation Commission to apply to a designated use of surface waters for contact recreation (Texas Water Commission, 1991):

Less than 200 colony forming units (CFU) per 100 milliliters (mL) of water as a geometric mean based on five samples collected over a 30-day period; and

Less than 400 CFU per 100 mL in more than ten percent of all samples, based on at least five samples, taken during any 30-day period; and

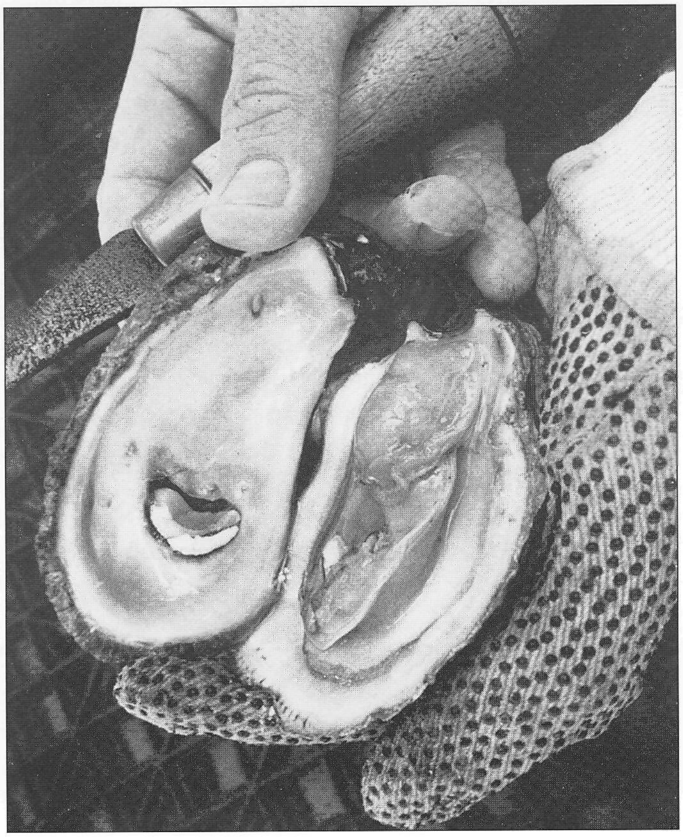
If ten or fewer samples are analyzed, only one sample can exceed 400 CFU per 100 mL.

According to the Texas Surface Water Quality Standards, "a designation of contact recreation is not a guarantee that the water so designated is completely free of disease-causing organisms."



Source: Galveston Bay National Estuary Program

Oysters—delicious seafood and basis of an important bay economy. Their harvest in Galveston Bay is regulated by the Texas Department of Health to reduce the risk of disease to consumers.



Source: Texas Sea Grant College Program

Health used the Total Coliform concentration obtained with the **Most Probable Number** (MPN) test. Subsequently, both total and fecal coliform MPN test data were used by Texas Department of Health until about 1983. Since 1983, only fecal coliform MPN data have been used by Texas Department of Health.

The Texas Natural Resource Conservation Commission does not regulate oyster harvest, but the *Texas Surface Water Quality Standards* maintain an "oyster waters" designation for water quali-

TEXAS DEPARTMENT OF HEALTH CATEGORIES FOR SHELLFISH GROWING AREAS

Approved areas lack significant contamination risk from human and/or animal fecal matter and are acceptable for direct market harvesting under all but very unusual situations.

Restricted areas are subject to some limited pollution, as indicated by a sanitary survey, and are unacceptable for harvesting without cleansing of the shellfish before entry into the market.

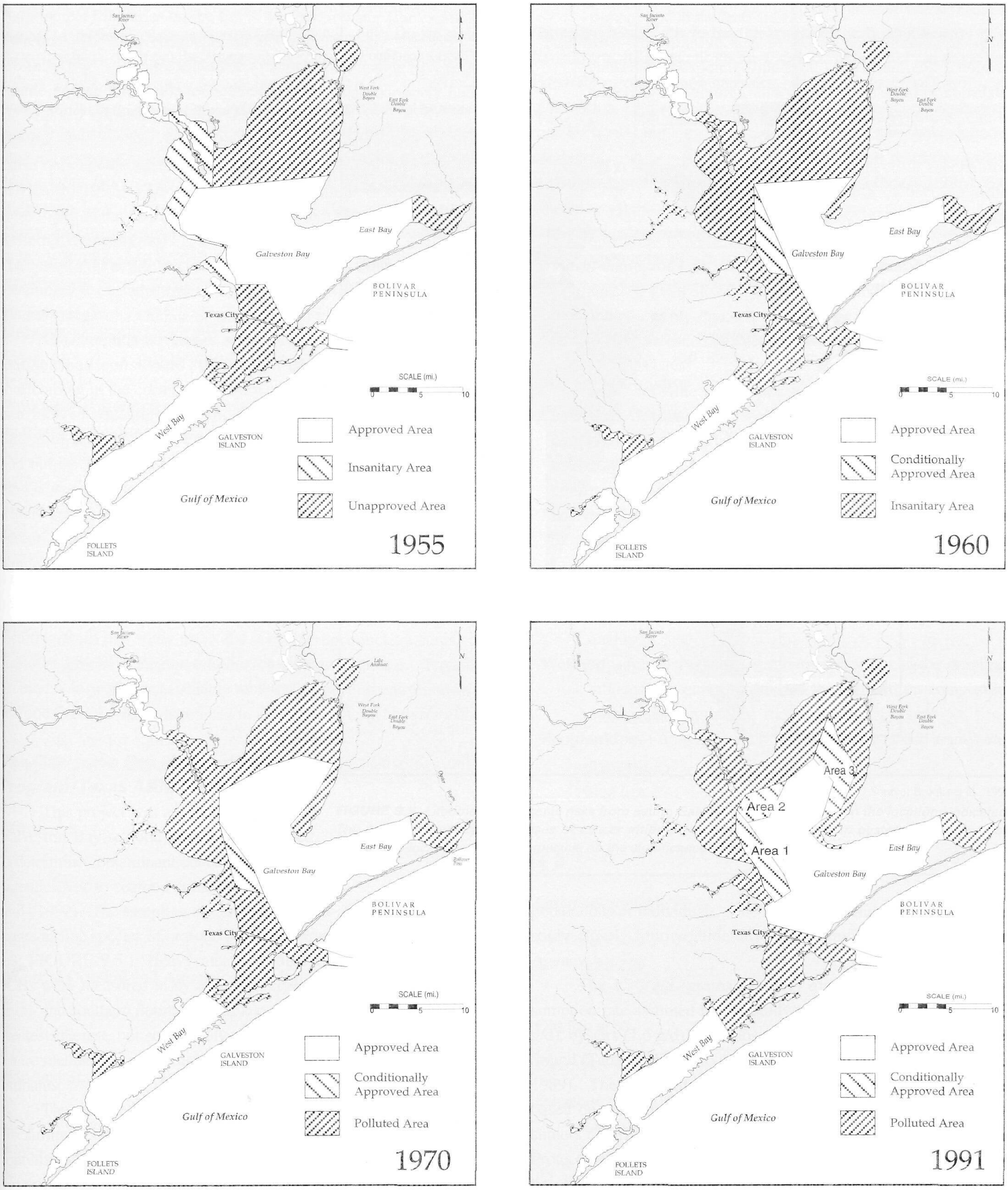
Conditionally Approved areas are subject to intermittent microbiological pollution which occasionally makes them unacceptable for harvesting– they are closed until conditions once again meet the approved area criteria.

Prohibited areas are small areas immediately surrounding sewage treatment outfalls discharging near the reefs; harvesting is not allowed from prohibited areas for any reason.

Texas law established the term *polluted area*, which is used in the Texas Department of Health orders and maps; however the criteria used by Texas Department of Health are the same as established for *restricted* areas in the National Shellfish Sanitation Program. Use of the term "polluted" applies only to the indicator tests and does not imply that waters are polluted according to common usage of the term.

ty protection of reefs. Oyster waters are to have a median less than 14 CFU per 100 mL of water, and not more than ten percent of the samples on a per station basis may exceed 43 CFU per 100 mL. The Texas Natural Resource Conservation Commission uses the membrane filtration test method in conjunction with the *Standards* (the *Standards* do not specify the use of MPN or membrane filtration methods). The difference between the membrane filter and MPN tests used by these two agencies have prevented their data from being strictly comparable.

Under the Texas Natural Resource Conservation Commission program, the following segments are designated as "oyster waters:" Segment 2420-Upper Galveston Bay; Segment 2422-Trinity Bay; Segment 2423-East Bay; Segment 2424-West Bay; Segment 2432-Chocolate Bay; Segment 2433-Bastrop Bay; Segment 2434-Christmas Bay; Segment 2435-Drum Bay; and Segment 2439-Lower Galveston Bay. These include essentially all of the open bay and some of the side bays. FIGURE 9.2 shows areas which exceeded the 14 CFU per 100mL criterion for oyster waters (but does not distinguish between areas that are designated for this use and areas which are not). Note that this analysis was based upon long-term



Source: Jensen, 1992

FIGURE 9.4. Four maps of shellfish harvest closures covering 36 years reveal that the area of the bay subject to closure has remained about the same over the years, in spite of constant regulatory and biological changes. The approximately 200,000 acres currently subject to closure (about half the bay) includes about 21 percent of the bay's oyster reefs. These maps are produced by the Texas Department of Health as a regulatory tool.

means (not medians, as required under the *Standards*).

Overall, the fecal coliform test used by the Texas Department of Health has been successful in assuring the good quality of shellfish from Galveston Bay sold for human consumption. However, limitations on the indicator approach discussed earlier in this chapter apply also to its use for oyster harvest regulation. Fecal coliform testing produces many false positive results, and fails to indicate risk from naturally occurring non-intestinal pathogens such as *Vibrio vulnificus*. Therefore, the validity of using only coliforms to regulate shellfish growing areas may be questionable (Jensen, 1992).

TABLE 9.1. Outbreaks of *Vibrio* Diseases Associated with Activities in Galveston Bay.

Age	Sex	County	Organism	Date	Outcome	Exposure	Activity
32	F	Galv.	*vulnificus*	9/83	recovered	water	sex
54	M	Harris	*parahaemolyticus*	6/86	recovered	wound	stepped on sharp object in water
57	M	Harris	*cholerae* non01	7/87	died	wound	pinched by crab
31	F	Wharton	*parahaemolyticus*	9/87	recovered	wound	walking
72	M	Harris	*vulnificus*	10/87	recovered	water	fishing
34	M	Brazoria	*cholerae* non01	8/89	recovered	wound	wade fishing
28	M	Harris	*vulnificus*	4/90	recovered	wound	windsurfing
4	F	Hender.	*vulnificus*	7/90	recovered	water	swimming
67	M	Harris	*vulnificus*	8/90	recovered	wound	fishing
46	M	Harris	*parahaemolyticus*	9/90	recovered	wound	swimming
78	M	Galv.	*parahaemolyticus*	5/91	recovered	wound	fishing
11	M	Galv.	*vulnificus*	8/91	recovered	water	playing in water

Source: Jensen, 1992

Shellfish Closure Trends

Maps are periodically produced by the Texas Department of Health as a regulatory tool to designate shellfish classification in Texas bays. There have been 40 shellfish classification maps issued for Galveston Bay by the Texas Department of Health since classification began in Texas. Four maps covering 36 years are shown in FIGURE 9.4.

Overall, the extent of the bay subject to shellfish harvest closure has remained about the same. However, this does not imply that conditions on the reefs themselves have necessarily remained the same–the maps reflect regulatory policies as well as field measurements. Besides elevated bacterial levels, areas closed over the years have resulted from changes in classification methods, testing procedures, and terminologies.

The history of shellfish sanitation for Galveston Bay illustrates these changes. Most of Trinity Bay, the northern and southwestern parts of Galveston Bay, the eastern part of East and West Bays, and Chocolate Bayou in West Bay were all originally classified as "unapproved oyster areas." In 1955, the unapproved area in Trinity Bay was reduced and the northern and western parts of Galveston Bay were changed to "unsanitary oyster areas" (FIGURE 9.4), causing a significant reduction in the unapproved area. In August of 1958, the unapproved areas in both Trinity Bay and Galveston Bay was once again expanded and the unsanitary area in Galveston Bay was once again labeled unapproved. However, two months later, the unapproved label was changed back to insanitary and the central part of Galveston Bay was reclassified as a conditionally approved oyster area. This classification remained the same in 1960. The 1960 map was changed slightly in 1970; most notable is the reclassification of unsanitary areas to prohibited or polluted areas after a 1969 Texas Department of Health comprehensive sanitary survey.

The most current classifications of Galveston Bay areas were issued by Texas Department of Health on November 1, 1991 (FIGURE 9.4). Portions of the eastern southwestern, western, northwestern, and northern shorelines were classified as "polluted" (see box on page 196 for explanation of this term). As for Trinity Bay, the northern, northeastern, and eastern portions were similarly classified. Also, all areas within a 50 yard radius of recreational cabins located in the bays were closed for shellfish harvesting. There were three areas that were classified as conditionally approved areas. These areas remain subject to classification changes based upon meteorological conditions which influence runoff.

In all, about half the bay's total area (about 200,000 acres) is subject to some form of shellfish harvest restriction by the Texas Department of Health. However, this area does not encompass a like proportion of the bay's economically important reefs; only about 21 percent of the oyster reefs in the bay are classified as prohibited or polluted.

Vibrio

The bacterial genus *Vibrio* contains 11 species which have been identified as pathogenic for humans, with the potential to cause extreme illness and sometimes death. Several *Vibrio* species pose a concern in coastal waters, the most common of which is *Vibrio vulnificus*, which can cause rapid and devastating infection in humans. These bacteria cannot be detected with the fecal coliform test, and therefore present a problem. *Vibrio vulnificus* exists naturally, being most common in warm waters with a temperature range of 10° to 30°C and a salinity range of five to 30 ppt – conditions representative of Galveston Bay.

Out of 176 *Vibrio* infections reported statewide between May of 1981 and September of 1991, 68 were reported in counties surrounding Galveston Bay, but only 12 were specifically identified as associated with Galveston Bay (Jensen, 1992; TABLE 9.1).

Contact recreation and food consumption were roughly equal sources of *Vibrio* infection, which accounted for 75 percent of the reported cases. No known regulatory mechanism exists to eliminate *Vibrio* risk; however the risk is small.

No evidence of temporal trend or relationship between *Vibrio* and fecal coliform bacteria data has been identified in Galveston Bay. A study performed in Cow Trap Lake, confirmed this conclusion (Texas Department of Health et al., 1990). Cow Trap Lake was selected because it exhibited elevated fecal coliform levels from non-human sources. Only low levels of pathogens were encountered in the lake, indicating a very low likelihood of transmission of disease from consumption of oysters from the lake. However, the oysters from the study area exceeded National Shellfish Sanitation Program market criterion (230 fecal coliform per 100 grams) in three of the four study phases.

TOXICANTS IN SEAFOOD ORGANISMS

In addition to being a critical type of information needed for reducing human health risks related to seafood consumption, data on concentrations of toxic chemicals in estuarine organisms are important indicators of ecosystem health.

A study by Brooks et al. (1992) provided information on toxic chemicals in finfish, shellfish, and birds in Galveston Bay, including the results of new field sampling. Supplementary information was also available from the National Oceanic and Atmospheric Administration National Status and Trends Study, a nationwide monitoring program for toxic chemicals in oysters and mussels. Oysters are good indicators of the presence of toxic chemicals in the environment because they do not move around, and because they filter large volumes of water and therefore have the potential to concentrate materials from the estuary.

Literally millions of compounds exist which could affect living organisms in an estuarine environment; those described below address several categories most likely to be present.

PAHs–Polynuclear Aromatic Hydrocarbons

PAHs are toxic compounds, some of which are carcinogens, that are "fat-binding" in living organisms and therefore have the potential to accumulate. PAHs are related to petroleum and combustion of petroleum and other organic compounds. Cycloalkanes, branched alkanes, n-alkanes, and aromatic compounds are the predominant hydrocarbons present in petroleum. Major sources in the coastal environment include drilling operations and petroleum production, transportation activities, coastal and/or riverine inputs, and

HYDROCARBON CONTAMINATION OF GALVESTON BAY: A SAMPLING OF STUDIES

Studies conducted from the Houston Ship Channel to San Luis Pass show that PAH concentrations in tissues of organisms in upper Galveston Bay are generally higher than in the lower bay. Total PAHs ranged from 11.0 to 236,000 ng/g (parts per billion), and included fluoranthene, pyrene, benzo(b)fluoranthene, benzo(e)pyrene, benzo(a)pyrene, chrysene, phenanthrene, and 1-methyl phenanthrene.

Oysters from polluted and unpolluted sites were analyzed between 1969 and 1971 (Fazio, 1971). Total PAHs ranged from 11 to 237 ng/g. Highest PAHs in tissues from contaminated sites were fluoranthene (7.8 ng/g), pyrene (6.5 ng/g), benzo(b)fluoranthene (2.2 ng/g), benzo(e)pyrene (2.1 ng/g).

Oysters collected in the late 1970s near Morgans Point, near the entrance of the Houston Ship Channel, had concentrations of benzo(a)pyrene from 0.07 to 0.14 ng/g (Murray et al., 1980). Oysters collected near San Luis Pass in the study did not have detectable concentrations of benzo(a)pyrene.

Oysters from Morgans Point, contained a total of 236,000 ng/g hydrocarbons (Ehrhardt, 1972). Concentrations of aromatic hydrocarbons were higher than those of alkanes.

Another oyster study from Morgans Point (Anderson, 1975) reported concentrations of 160,000 ng/g total hydrocarbons. Oysters collected a few miles away from the Houston Ship Channel had lower concentrations (26,000 ng/g), while oysters collected in West and East Bays had less than 2,000 ng/g of total hydrocarbons in their tissues.

Oysters collected from Galveston Bay from 1976 - 1978 as part of a nationwide study (Farrington et al., 1980) contained 940 ng/g fluoranthene and 1,010 ng/g pyrene.

A 1988 study (Fox, 1988) reported that total PAHs were higher at sites located closer to urban areas. Oysters collected near the Houston Yacht Club (615 ng/g) and Confederate Reef near the City of Galveston (610 ng/g), had annual average concentrations that were higher than samples collected from Todd's Dump (134 ng/g) located in the middle of Galveston Bay, and Hanna Reef in East Bay (111 ng/g). Pyrene, fluoranthene, chrysene, phenanthrene, and 1-methyl phenanthrene were the most frequently detected PAHs.

combustion of all forms of fossil fuels, including atmospheric fallout of the combustion products. PAHs are also introduced into the environment from some organic chemical reactions, and fires–both natural and from waste incinerators or other combustion sources. Because of the persistent and "fat-binding" nature of PAHs, it is not surprising that they have been frequently detected as a widespread (as opposed to localized) pollutant.

Brooks et al. (1992) conducted a survey of five species of seafood organisms from four locations in the bay (see FIGURE 9.5 and the section on seafood risk page 202). The study analyzed for 24 individual PAHs and revealed total PAHs ranging from nondetectable to 1253 ng/g (parts per billion). Oysters had higher total PAH concentrations than fish (all four sites) and crabs (all except Hannah Reef). Concentrations found in the study were within the range of concentrations reported for oysters for Galveston Bay as part of the National Status and Trends Program, which found PAHs in oysters to be among the highest 25 percent throughout the Gulf of Mexico.

The Brooks study also revealed some information about the origin of PAHs. Alkylated PAHs were low at all sites when compared to total PAHs (except at Eagle Point), indicating a combustion source. Alkylated and high molecular weight PAHs in fish from Eagle Point probably resulted from the *Apex* barge oil spill of 1990.

A total of more than ten additional studies of oysters, fish, and birds from Galveston Bay generally indicated that PAH concentrations in tissues of these organisms were higher in upper Galveston Bay than in the lower bay (see box on page 199). For example, a 1987 study (King et al., 1987) reported on double-crested cormorants, a fish-eating waterbird near the top of the food web which winters on the upper Houston Ship Channel. At the beginning of the wintering season, birds contained only naphthalene and fluoranthene. At the end of the wintering season, birds contained eight aromatic hydrocarbons.

Results of the National Status and Trends Study (findings summarized in Brooks et al. 1992) show that PAHs measured in oysters from upper Galveston Bay and near the City of Galveston were ten to one hundred times higher in concentration than for non-urban portions of the bay. Overall concentrations ranged from 54 to 2,400 ng/g. Of interest, the prevalence of two particular PAHs (pyrene and fluoranthene) suggested that the major source of PAHs in the Galveston Bay area was combustion products.

Chlorinated Hydrocarbons

Most attention to this class of toxic compounds has been focused on pesticides and PCBs (polychlorinated biphenyls). Pesticides include DDT (and related degradation compounds DDD and DDE); aldrin (which degrades to dieldrin); and heptachlor (which degrades to heptachlor epoxide, endrin, and lindane). The use of these toxic and persistent compounds has been banned or severely restricted in most developed countries because of their tendency to bioconcentrate in food chains.

The study by Brooks et al. (1992) analyzed for a suite of chlorinated hydrocarbons and PCBs, including total BHCs, total chlordane, dieldrin, total DDTs, and total PCBs. The findings from this project are given in TABLE 9.2.

Other studies also reveal that, in spite of the current bans, a variety of organochlorine residues exist in Galveston Bay organisms and sediment and water samples. About 12 different studies on chlorinated hydrocarbons in organisms from Galveston Bay have been conducted (see box on page 201), with a good review provided in Brooks, et al. (1992). Compounds most commonly found were PCBs, DDT metabolites, and occasionally, dieldrin, HCB and chlordane. Of these, PCBs are perhaps of most concern, due to the results of the Galveston Bay National Estuary Program seafood risk analysis study, also reported in this chapter.

Dioxin and Furans

These compounds (polychlorinated dibenzo-p-dioxins and

TABLE 9.2. Chlorinated Hydrocarbons in Oyster, Crab, and Fish Tissue from Four Sites in Galveston Bay.

Compound	Findings
BHCs	Higher in oysters than crabs or fish tissue; highest in fish livers. Highest at Morgans Point (8.85 ng/g); similar at Eagle Point, Hanna Reef, and Carancahua Reef. Levels for oysters within range reported by National Status and Trends Program.
Chlordane	Similar in fish, crabs, and oysters; higher in fish livers. Highest at Morgans Point (58 ng/g) and decreased down-bay. Levels for oysters within range reported by National Status and Trends Program.
DDT	Similar in fish, crabs, and oysters; higher in fish livers. Highest at Morgans Point (average 87 ng/g) and decreased down-bay. Levels for oysters within range reported by National Status and Trends Program (which found DDT in Galveston Bay oysters among the highest 25 percent of concentrations Gulf-wide).
Dieldrin	Similar in fish and oysters; lower in crabs; highest in fish livers. No down-bay decreasing trend (range two to 11 ng/g). Levels for oysters within range reported by National Status and Trends Program .
PCBs	Similar in oyster and fish, slightly higher in crabs; much higher in fish liver. Decrease from Morgans Point down-bay (range 176–612 ng/g). Levels for oysters within range reported by National Status and Trends Program.

Source: Brooks et al., 1992

polychlorinated dibenzofurans) are extremely persistent in the environment, and can affect human health at low concentrations. As a result of dioxin found in seafood organism tissue in Galveston Bay, a seafood consumption advisory for catfish and blue crabs was issued by the Texas Department of Health in September, 1990 for a portion of the upper bay system. Under the advisory, no one should consume more than one seafood meal (not to exceed eight ounces) each month from this area; and women of child-bearing age and children should not consume *any* catfish or blue crabs from this area. The sea catfish to which the advisory applied is not generally consumed.

One study in the late 1980s reported concentrations of 54.8 pg/g (parts per trillion) dioxin in blue crabs and 3.2 pg/g in blue catfish collected at the San Jacinto Monument. Further downstream at Morgans Point, concentrations were 14.8 pg/g in sea catfish and 6.2 pg/g in oysters. A follow-up study was conducted in 1990, finding up to 3.97 pg/g in crabs, oysters, and red drum in upper Galveston Bay.

Trace Metals

Metals in Galveston Bay organisms rarely differ substantially from levels noted for other Gulf of Mexico estuaries. For example, the average concentrations of cadmium, chromium, copper, manganese, and lead in oysters collected from six different sites under the National Status and Trends Program differed by ten percent or less from the Gulf-wide average. Silver was 23 percent higher, nickel 16 percent higher, and selenium was 14 percent higher than the Gulf-wide averages. (Apparently, the Galveston Bay oysters exceeded the Gulf-wide average because of low selenium oysters taken in Mississippi and Florida). Oysters from other Texas and Louisiana bays are also similar in arsenic and mercury content to those in Galveston Bay. Zinc, however, was 35 percent higher in Galveston Bay oysters than the Gulf-wide average. Concentrations of zinc in oysters showed a clear correlation with human activities, whereas other metals did not.

Brooks et al. (1992) analyzed fish, crabs, and oysters for a suite of trace metals. They found concentrations similar to the National Status and Trends findings, excepting zinc. Values for

SOME STUDIES OF CHLORINATED HYDROCARBONS IN GALVESTON BAY

These toxic compounds, mainly persistent pesticides, tend to accumulate through the food chain to high levels. Their persistence has resulted in their continued presence in Galveston Bay, even though many are out of general use due to product bans enacted as their ecosystem effects became widely known beginning in the late 1960s.

Tests on oysters collected 1965 - 1972 (Butler, 1973) determined that DDT residues were the most commonly detected organochlorines. Overall averages for DDT in oysters were 6.16 ng/g for oysters from Trinity Bay, and 23.9 ng/g for those from Galveston Bay. Dieldrin was the second most frequently encountered chlorinated pesticide–oysters averaged 14.5 ng/g, while the average for oysters from Trinity Bay was lower (2.86 ng/g). Similar concentrations of dieldrin were reported for clams from Trinity Bay in 1975.

Oysters collected at four sites scattered throughout the bay contained detectable concentrations of PCBs, DDT residues, dieldrin, transnonachlor, alpha-chlordane, and heptachlor epoxide. Oysters from the Houston Yacht Club reef, in upper Galveston Bay, had higher concentrations of organochlorides than oysters from the other sites (Hanna Reef, Todd's Dump, and Confederate Reef). HCB and PCP (two other chlorinated hydrocarbons) have also been found in oysters from Galveston Bay at Morgans Point.

A fish tissue study conducted during the mid-1970s (Strawn et al., 1977) found PCB concentrations of 50 - 500 ng/g in mullet, croaker, and Florida pompano collected in Trinity Bay. Lower concentrations were found in juvenile croakers (nine to 43 ng/g).

Studies in the late 1980s (King, 1989a; 1989b) found significant concentrations of chlorinated hydrocarbons in fish that are food items for two birds that use Galveston Bay: black skimmer and olivaceous cormorant. These fish were tidewater silverside, sheepshead minnow and striped mullet.

Other studies were conducted in the mid- to late 1980s on chlorinated pesticides in tissues of waterbirds nesting in upper Galveston Bay, including olivaceous and double-crested cormorants, laughing gulls, and black skimmers (King and Krynitsky, 1986; King et al., 1987). PCB concentrations ranged from 930 to 4,430 ng/g, and dieldrin concentrations ranged from 100 - 160 ng/g. These concentrations are one to two orders of magnitude higher than those in fish. Since these fish-eating birds are at the top of the aquatic food chain, bioaccumulation of organic contaminants is expected. Chlordane, HCB, and heptachlor epoxide were also found to be present in waterbird tissues.

Source: Galveston Bay National Estuary Program

Seafood in the raw. Dumped on the deck of a shrimp trawler, the crabs, shrimp, and fish of Galveston Bay illustrate the basis for a thriving seafood economy. The risk associated with eating any seafood item from the bay can be estimated, but the decision about what to eat can only be made by the individual consumer.

zinc were lower in the study by Brooks et al., and did not correlate with urban and industrial areas, as determined in the National Status and Trends work. In general, Brooks et al. found no strong relationship between metals in fish flesh and proximity to industrialization (or any other geographical trend). Tissue concentration ranges determined by Brooks et al. were: silver 0.09–0.14 μg/g; arsenic 0.45–0.89 μg/g; cadmium 0.168–0.310 μg/g; chromium 0.022–0.211 μg/g; copper 9.888–33.819 μg/g; mercury 0.079–0.123 μg/g; nickel 0.04–0.20 μg/g; lead 0.04–0.06 μg/g; selenium 0.88–2.27 μg/g; and zinc 68.7–115.2 μg/g.

Crocker et al. (1991) reported limited analyses for metals in fish and crabs from nine stations in the Houston Ship Channel during two time periods. Fish analyzed included sea catfish, spot, white bass, striped mullet, red drum, and spotted seatrout. Crabs were also analyzed. Tissues were analyzed for arsenic, antimony, chromium, copper, cyanide, selenium, silver, and zinc. Concentrations of arsenic ranged from 0.25 to 4.2 mg/kg, antimony ranged from 3.3 to 4.2 mg/kg, chromium ranged from 0.48 to 12 mg/kg, copper ranged from 0.48 to ten mg/kg, cyanide from <0.51 to 1.9 mg/kg, selenium from 0.61 to 14 mg/kg, silver from 0.48 to 1.5 mg/kg and zinc from 4.8 to 51 mg/kg. Antimony, arsenic and selenium concentrations exceeded Environmental Protection Agency fish tissue criteria, while chromium, copper, cyanide, silver, and zinc concentrations were below the Environmental Protection Agency criteria.

Arsenic and mercury in Galveston Bay oysters collected under the National Status and Trends Program were less than one-half the Gulf-wide average but the Gulf-wide averages are greatly affected by several sites in Florida that produce oysters greatly enriched in arsenic and mercury, and by a site in Lavaca Bay which is enriched in mercury. Oysters from other Texas and Louisiana bays are similar in arsenic and mercury content to those in Galveston Bay.

HUMAN HEALTH RISKS ASSOCIATED WITH SEAFOOD CONSUMPTION

Seafood from Galveston Bay is quite popular. Texas A&M figures from several recent studies indicate that Galveston Bay seafood landings account for more than 30 percent of the state-wide bay system total (Brooks et al., 1992), and more than 65 percent for oysters (Haby et al., 1989). Yet the question is asked again and again, "is it safe to eat?"

Generally, but not always, the answer is "yes." This is especially true for commercially-caught fish and shellfish, which tend not to come from the most contaminated portions of the upper estuary and which are subject to regulation. But this issue requires some qualification, presented in this section. Seafood from the bay contains generally low but variable concentrations of toxic chemicals that can represent health risks of some concern under certain conditions.

Seafood Advisories

Two **seafood advisories** (see box below) have recently been issued for the Galveston Bay system. The first was based upon dioxin contamination in a limited area of the upper bay. The Texas Department of Health advised that no one should consume more than one seafood meal (not to exceed eight ounces) each month from this area; and that women of child-bearing age and children should not consume any sea catfish (rarely consumed anyway) or blue crabs from this area. The advisory was issued because of low levels of dioxin found in samples of these two species, 3.2 parts per trillion to 14.8 parts per trillion. Samples of other species did not show levels of dioxin above the low levels which trigger an advisory under risk assessment protocols (Thompson, 1993a). This advisory was conservative in the sense that most of the data on tissue concentrations of dioxin were below the Environmental Protection Agency screening level, and none of the samples exceeded the Federal Drug Administration guidelines for issuing a warning.

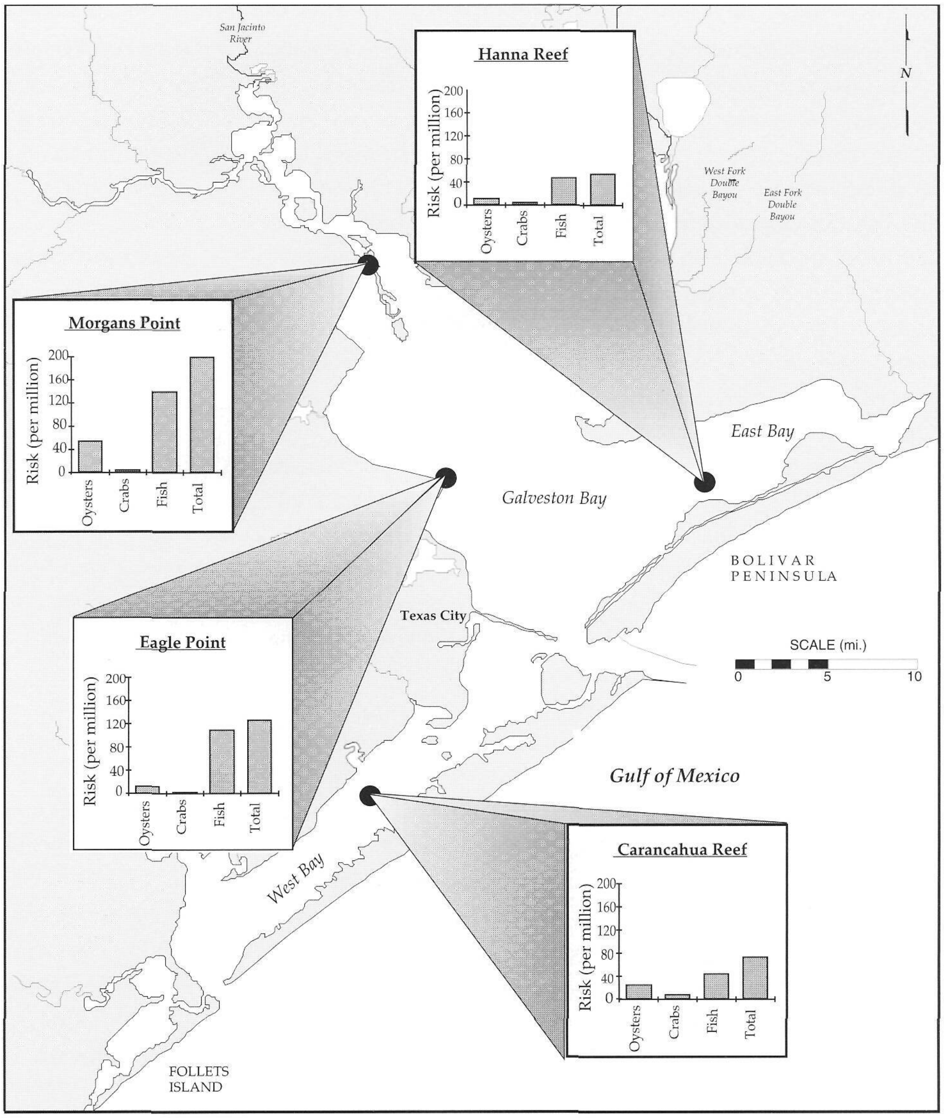
The second advisory was based on three toxic compounds

TEXAS DEPARTMENT OF HEALTH SEAFOOD ADVISORIES

Seafood consumption advisories or area closures are issued by Texas Department of Health under the *Aquatic Life Law.* When indications of a risk to human health are brought to the agency's attention, a *risk assessment* is conducted based on information provided. If a risk assessment indicates an imminent health hazard, the affected area is declared *Prohibited* for affected species, and taking those species from the area becomes a violation of law. An *imminent hazard* would exist if just one or a few meals would result in an acute health problem. If a less immediate hazard exists–one created by longer term consumption habits–a *Consumption Advisory* would be issued with consumption recommendations for affected populations.

discovered in fish from Clear Creek, one of the principal tributaries on the bay's western shoreline. The three chemicals, all of which are industrial solvents, included dichloroethane and trichloroethane–both of which are believed to cause cancers of the liver and kidneys–and carbon disulfide, which can cause nervous disorders (Texas Department of Health, 1993). The contaminated fish were found in the vicinity of the former Brio Refining Company, a U. S. Environmental Protection Agency Superfund site where a cleanup of toxic industrial compounds is in the early stages.

Consumption advisories serve to protect seafood consumers. However, one shortcoming in the current regulatory system is a lack of routine tissue monitoring to determine risks. Therefore, a study was carried out by Texas A&M University to sample Galveston Bay seafood organisms from widely scattered locations, and estimate the potential risk to consumers. Contaminant concentrations in these seafood samples were reported above; below are reported the results of risk estimation. The risk estimates resulting from this study exceeded a benchmark used by EPA Region 6 to flag possible problems, for consumers of large amounts of seafood from the upper bay.



Source: Brooks et al., 1992

FIGURE 9.5. *Lifetime carcinogenic risks from eating Galveston Bay seafood from the locations indicated. The graphs show expected cases of cancer attibuted to toxic contaminants in oysters, crabs, and fish from these locations. For a perspective on the significance of these findings, see TABLE 9.7.*

The Galveston Bay National Estuary Program/Texas A&M Seafood Study

This project was a screening survey of Galveston Bay seafood organisms, designed to determine contaminant concentrations and potential risk to seafood consumers (Brooks et al., 1992). The sampling design called for the analysis of contaminants in five species of seafood organisms from four sites (TABLE 9.3; FIGURE 9.5.) Heavy metals, hydrocarbons, pesticides, and PCBs were measured in oysters, blue crabs, spotted seatrout, black drum, and southern flounder. Edible portions of the seafood were of greatest interest, but some analyses were conducted for fish livers, where metabolism and a high lipid content tend to concentrate contaminants.

The project relied on sensitive analytical methods that can discriminate trace amounts of specific contaminants. Based on contaminant levels found in the seafood organisms, risk to consumers was estimated using a scientific procedure to determine the probability of adverse health effects from eating seafood contaminated with the toxic agents of concern. The chief goal was to characterize the types of hazards associated with the contaminants and to estimate the probability that those hazards could affect exposed populations or individuals. The risk assessments calculated for this study closely follow guidelines of the Environmental Protection Agency.

The 15.0 g/d (grams per day) *average* total seafood consumption rate assumed for the study was partitioned into fish (12.3 g/d), oysters (1.6 g/d) and crabs (1.1 g/d) based on data from Puget Sound (Tetra Tech, 1988) and Texas seafood statistics (Quast et al., 1989). The *high* seafood consumption rate used in the study was based on consumption estimates for the top five percent of consumers (TABLE 9.4). It should be noted that the Environmental Protection Agency uses a value of 6.5 g/d as an average consumption rate. The Environmental Protection Agency figure is derived from a national average for seafood consumption while Brooks' consumption figure of 15.0 g/d was intended to more accurately reflect local seafood consumption rates.

It is important to note that risk assessment is a controversial and evolving field (see box on page 205 for a discussions of some of the specific limitations and assumptions). Risk estimates rely on statistical averages for an entire population; the more an individual differs from the average the less they apply. These estimates also have considerable uncertainty. They depend upon experimental and epidemiological information about hazardous properties of chemicals, combined with information concerning the magnitude of human exposure to these chemicals. Some researchers have suggested that the risk assessment procedures in use today for chemical contaminants are so conservative that they may be invalid (Ames et al., 1987; Lehr, 1990), implying that the vast majority of seafood from Galveston is safe to eat (Thompson, 1993b).

In spite of their controversial nature, risk assessment studies provide us with the only method we have to assess the safety of different activities like consuming seafood. "Safety" is a relative term referring to an activity with acceptably low risk–but "acceptably low" to one person may not be to another. Therefore, the significance of risk can only be determined by each individual, reviewing the best information available, and comparing one kind of personal risk to another. An understanding of risk is also necessary to determine how safety can be increased by addressing the sources of contaminants.

Two types of risks were evaluated in the Galveston Bay National Estuary Program/Texas A&M study: cancer risks and non-cancer risks. Cancer risk (primarily from organic toxicants) is expressed as the probability for a 154-lb human to contract cancer as a result of eating the assumed amount of seafood over a 70-year lifetime. For example, risk expressed as 7.4×10^{-5} (the cumulative risk associated with seafood from Carancahua Reef) equates to one person in 740,000 contracting cancer as a result of eating the seafood. The non-cancer health hazard (primarily from trace metals) is expressed as a ratio of the dose of contaminants from the seafood portion to a "reference dose" established as a threshold for human health concern. A value of greater than one represents a potential concern.

TABLE 9.3. Categories of Compounds Potentially Contributing to Risk to Consumers of Galveston Bay Seafood, Based on Preliminary Risk Estimates.

Priority	Toxic Class	Chemical or Compound Group
High	Carcinogens	Arsenic
		Polycyclic Aromatic Hydrocarbons (PAHs): anthracene; thioanthene; pyrene; benzo(a)pyrene; benzo(b)fluoranthene; chrysene; benzo(k)fluoranthene
		Polychlorinated Biphenyls (PCB)
		DDT and derivatives (DDD and DDE)
	Noncarcinogens	Cadmium, Lead, Phenanthrene
Medium	Carcinogens	Benzene hexachloride (BHC)
		Chlordane
		Dieldrin
	Noncarcinogens	Mercury, Copper
Low	Carcinogens	
	Noncarcinogens	Antimony, Chromium, Nickel, Selenium, Silver, Zinc

Source: Brooks et al., 1992

Seafood Consumption Risk Findings

For cancer risk, consumers eating *average* amounts of seafood from some locations in Galveston Bay (15 g/day, or about a pound per month) were at risk above a benchmark level of 1×10^{-4} (one in 10,000) previously used by the Environmental Protection Agency to flag possible problems (equal to 100 extra cancer deaths per million people). The risk from oysters at Morgans point and fish at Morgans and Eagle Points was estimated to be higher than risk from oysters or fish from other locations (TABLE 9.5 and FIGURE 9.5). These risks were higher in the upper Bay, where effects from the upper Houston Ship Channel and the Trinity River would be expected (see FIGURE 9.5). In comparison to average levels of seafood consumption, the person who consumes *large quantities* of seafood (147.3 g/day or about ten pounds per month) would exceed the Environmental Protection Agency benchmark risk at all sites examined in the study.

TABLE 9.4. Average and High (95th Percentile) Consumption Rates for Fish, Crabs and Oysters Used in Risk Assessment Calculations.

Seafood Category	Average Value	High Exposure Value
Fish	12.3 g/day	94.5 g/day
Oysters	1.6 g/day	31.3 g/day
Crabs	1.1 g/day	21.5 g/day
Total	**15.0 g/day**	**147.3 g/day**

Source: Brooks et al, 1992

Most of the cancer risk was associated with PCB and PAH concentrations, with PCBs usually providing a larger portion of the overall risk. Analysis of the specific PAH compounds indicated that most of the PAHs originated from combustion products (such as engines, burning, etc.) that were not directly associated with release of oil to the bay (Brooks et al., 1992).

The Galveston Bay National Estuary Program study did not include dioxin, due to the costs of dioxin analysis. However, a previous Environmental Protection Agency study (Crocker and Young, 1990) addressed tetrachlorodibenzo-p-dioxins and -dibenzofurans (dioxins and furans) at sites in Arkansas, Louisiana and Texas. They estimated a risk level for 2,3,7,8-tetrachlorodibenzo-p-dioxin of 2.14×10^{-4} for sea catfish at Morgans Point, 4.6

RISK ASSESSMENT IN THE GALVESTON BAY STUDY: SOME LIMITATIONS

Determining the concentration of a chemical in edible portions of seafood

Sources of uncertainty in the tissue analyses included:

Organisms were collected during an unusual flood, possibly affecting "normal" fish distribution and contaminant levels;

Sampling took place over a several month period, and included some alternates species when sampling success was poor; and

Sampling coincided with the Apex barge spill–some tissue samples clearly showed petroleum compounds related to the spill.

Choosing assumptions for average seafood consumption rates

For the entire consumer population: 15 g/day (about a pound per month) for marine seafood corresponding to the amount cited in the *Texas Surface Water Quality Standards.*

For high-amount consumers: 147.3 g/day (about ten pounds per month), corresponding to the top five percent of consumers (including subsistence fishermen).

Determining how much of the chemical is absorbed from seafood eaten

All the chemical present in edible portions was assumed to be absorbed by the consumer. In reality, preparation, cooking, and digestive efficiency would tend to reduce the effective dose.

The study also assumes that the average consumer will get all of their seafood from Galveston Bay and will eat this seafood every day for 70 years. In reality, we get seafood from many different bays and oceans, and many people do not eat seafood from this area for a total of 70 years.

Determining average consumer weight

The project assumed 70 kg (154 lb) based on standard Environmental Protection Agency methods. Generally, a smaller person would be more susceptible to a given chemical dose.

Determining cancer-causing potency

The project used the most sensitive five percent of the general population to the given chemical. Dose-response relationships upon which these assumptions were based have other elements of uncertainty:

Potency information is sometimes derived from animals studies, which may react differently from humans. For example, it takes 5,000 times the dose of dioxin that is lethal to a guinea pig to have the same effect on a hamster (Tschirley, 1986).

Other potency information is derived from knowledge about similar chemicals.

Adding the effects from multiple chemicals

The risk from different compounds were added together in this study to yield a cumulative risk. However, some researchers question the assumption that potential carcinogenic effects of multiple chemicals are additive. For example, the Environmental Protection Agency's Science Advisory Board recently recommended that the risk from potential carcinogens should be considered additive only when it is demonstrated that they have the same mechanisms of action and the same receptor organ. This would have the effect of reducing the risk estimates produced by the Galveston Bay National Estuary Program/Texas A&M study. On the other hand, not all compounds were included in the study, for example dioxin (known to be present in the upper estuary) was not included because of analytical expense and the existence of previous studies. Including additional compounds would tend to increase the estimates of risk.

x 10^{-5} for blue catfish at San Jacinto Monument, 8.8 x 10^{-5} for oysters at Morgan's Point, and 7.93 x 10^{-4} for blue crabs at San Jacinto Monument.

The Environmental Protection Agency study assumed a consumption rate of 6.5 g/d, while the Galveston Bay National Estuary Program study assumed consumption rates of 15 g/d for the average consumer and 147.3 g/d for high seafood consumers. Thus, the two studies are not directly comparable, but added together, would yield an estimate higher than those presented in this chapter. Calculating an average of the four Environmental Protection Agency risk estimates, and adding this to the estimates for risk to average and high consumers of seafood from Morgans Point (Brooks et al., 1992), yields estimates of 3 X 10^{-4} for average consumers and 2.6 X 10^{-3} for high consumers. This estimate includes consideration of arsenic, PAHs, BHC, total chlordane, dieldrin, total DDTs, total PCBs, and dioxins and furans.

For non-cancer risk, Brooks et al. indicated no exceedences of health-based standards at average seafood consumption rates, but some exceedences for high seafood consumption rates, primarily related to oysters (TABLE 9.6). There were no significant differ-

TABLE 9.5. Carcinogenic Risk Estimates for Galveston Bay Seafood from Four Different Areas of the Bay.

Site	Fish Consumption Rate Average	Fish Consumption Rate High	Oysters Consumption Rate Average	Oysters Consumption Rate High	Crabs Consumption Rate Average	Crabs Consumption Rate High
Hanna Reef	4.1×10^{-5}	3.1×10^{-4}	9.5×10^{-6}	1.9×10^{-4}	3.6×10^{-6}	7.0×10^{-5}
Morgans Point	1.4×10^{-4}	1.0×10^{-3}	5.5×10^{-5}	1.3×10^{-3}	4.9×10^{-6}	9.6×10^{-5}
Eagle Point	1.1×10^{-4}	8.2×10^{-4}	1.3×10^{-5}	2.5×10^{-4}	2.7×10^{-6}	5.3×10^{-5}
Carancahua Reef	4.3×10^{-5}	3.3×10^{-4}	2.5×10^{-5}	4.8×10^{-4}	6.5×10^{-6}	1.3×10^{-4}

Source: Brooks et al., 1992

TABLE 9.6. Non-Carcinogenic Risk Index Estimates for Galveston Bay Seafood from Four Different Areas of the Bay.

Site	Fish Consumption Rate Average	Fish Consumption Rate High	Oysters Consumption Rate Average	Oysters Consumption Rate High	Crabs Consumption Rate Average	Crabs Consumption Rate High
Hanna Reef	0.10	0.79	0.10	1.95	0.01	0.21
Morgans Point	0.11	0.84	0.14	2.76	0.02	0.30
Eagle Point	0.11	0.82	0.12	2.35	0.01	0.24
Carancahua Reef	0.10	0.77	0.17	3.31	0.03	0.50

Source: Brooks et al., 1992

TABLE 9.7. Cumulative Risk Estimates[1] for Chemicals of Concern Measured in Fish, Crabs, and Oysters from Galveston Bay.

Site	Non-Carcinogenic Risk Index Values[2] Average Consumption	Non-Carcinogenic Risk Index Values[2] High Consumption	Carcinogenic Risk Values[3] Average Consumption	Carcinogenic Risk Values[3] High Consumption
Hanna Reef	0.21	**2.95**	5.4×10^{-5}	**5.7×10^{-4}**
Morgans Point	0.27	**3.90**	2.0×10^{-5}	**2.3×10^{-3}**
Eagle Point	0.24	**3.41**	**1.3×10^{-4}**	**1.1×10^{-3}**
Carancahua Reef	0.24	**4.58**	7.4×10^{-5}	**9.4×10^{-4}**

Source: Brooks et al. 1992

[1]Multiple chemical exposure via multiple categories of seafood for the chemicals measured in this study. Any risk from dioxins should be added to these values to give a total cumulative risk.
[2]All trace metals except arsenic were evaluated.
[3]Chemicals evaluated were arsenic PAHs BHC, chlordane, dieldrin, DDT and its derivatives, and total PCBs
BOLD means risk estimate exceeds EPA benchmark level

ences in the non-carcinogenic risk level between any of the locations for fish, oysters or crabs. While the level of chemical contaminants in oysters was higher than fish, the average lifetime risk was about the same because the amount of fish consumed was assumed to be higher. TABLE 9.7 summarizes both cancer and non-cancer risks for all four locations.

What do the risk levels mean? To place them in perspective, consider that approximately 25 percent of all people contract cancer. Performing some activity at the 1×10^{-4} benchmark risk level will increase the overall probability that one contracts cancer from 0.2500 (25 percent) to 0.2501 (infinitesimally higher). In other words, we are subject to lots of cancer risk anyway. TABLE 9.8 (adapted from Wilson, 1979; Crouch and Wilson, 1982; Lehr, 1990) provides some examples of common activities and the associated cancer risks, including consumption of Galveston Bay seafood.

SUMMARY

Open-water portions of Galveston Bay generally conform to Texas water quality criteria for contact recreation. Areas where recent fecal coliform bacteria levels exceeded the state standard are in western, developed tributaries of the bay: Buffalo Bayou Tidal, Clear Creek Tidal, and Dickinson Bayou Tidal. In some of these areas, contact recreation is common and unregulated. Bacteria data show no increasing trend that could be associated with human activities in the watershed.

Source: Texas Sea Grant College Program

Galveston Bay's finest. Future comprehensive management of Galveston Bay can assure we maintain the ecological and human life support capacity of this premier estuary.

While many regulatory changes have taken place over the years in shellfish harvesting regulation, the area of the bay subject to shellfish closure has remained about the same for four decades. Wet weather runoff appears to be the most significant source of bacteria, but concentrations in the open bay tend to be localized and of short duration. For example, many of the conditionally approved areas for oyster harvesting are reopened within a few days after heavy rain events. Many of the shellfish closures result from either a small portion of the data exceeding higher values, generally after rains, or a judgment made about the potential for upland facilities to introduce pathogens.

As a water quality and public health indicator, the fecal coliform test currently being used has significant limitations. While it has a long history of protecting public health, limitations result from the frequent presence of naturally occurring bacteria which "pass" the test and lack of a good correlation with both true pathogens from animal wastes and with naturally occurring pathogens, particularly *Vibrio*.

No total prohibitions on seafood consumption due to toxic contamination currently exist in Galveston Bay. However, a seafood consumption advisory for catfish and crabs was issued by the Texas Department of Health in September 1990 for the upper bay system and upper Houston Ship Channel as a result of dioxin measured in these species. A second advisory was issued in late 1993 for all fish from Clear Creek, as a result of several industrial chemicals found in fish tissue. Currently lacking for the Galveston Bay system is a routine seafood testing and risk assessment program that would effectively identify health issues.

A one-time risk assessment study of seafood organisms from four locations in the bay indicated that the upper bay system (Morgans Point) was the most contaminated site, with contamination generally decreasing down-bay. The risk associated with consumption of average amounts of seafood sometimes exceeded a benchmark risk level used by EPA Region 6 to flag possible problems. For high–consumption populations, risk exceeded the benchmark at all locations. PAHs and PCBs appear to be responsible for most of the carcinogenic risk associated with consumption of Galveston Bay seafood, with oysters the most contaminated species and crabs the least.

In reality, science cannot currently determine the true risk to bay users or seafood consumers resulting from contamination–either by bacteria or by toxic materials. Decisions about individual risk remain with the individual, with risk estimates available as one source of information.

TABLE 9.8. Comparative Risks Associated with Various Activities.

Activity	Risk Level	Additional Cancer Deaths per Million People Doing Activity	Source of Risk
One Chest X-Ray	1.0×10^{-6}	1	Cancer by Radiation
Eating Galveston Bay Seafood Every Day for 70 yrs. (Average Consumption)	$\mathbf{7.0 \times 10^{-5}}$	**70**	**Cancer from PCBs, PAHs**
Eating Four Tablespoons of Peanut Butter Every Day for 70 Years	5.6×10^{-4}	560	Cancer from Aflatoxin (natural carcinogen)
Eating Galveston Bay Seafood Every Day for 70 yrs. (High Consumption)	$\mathbf{1.2 \times 10^{-3}}$	**1200**	**Cancer from PCBs, PAHs**
Breathing Air Pollution in New York for 70 yrs.	1.3×10^{-2}	12,775	Cancer from Air Pollution
Smoking for 70 yrs.	2.1×10^{-1}	210,000	Cancer, Heart Disease

Source: adapted from Wilson, 1979; Crouch and Wilson, 1982; Lehr, 1990

FOR MORE INFORMATION

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