CHAPTER 2

WATER QUALITY OF THE GULF OF MEXICO

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2.1 INTRODUCTION

Water quality is a vital characteristic in determining how societies and humans use and value aquatic environments and associated natural resources. Coastal and offshore environments are some of the greatest assets of the United States, and much of their value is critically dependent on the quality of the water they contain (Pew Oceans Commission 2003; U.S. Commission on Ocean Policy 2004). The Gulf of Mexico accounts for approximately 13.5 percent (%) of the U.S. coastline. A considerable portion of the economies of the states that border the Gulf of Mexico—Texas, Louisiana, Mississippi, Alabama, and Florida—are dependent on resources and services provided by the maritime environment. Water quality is a derived concept that is usually assessed based on a water body's suitability for ecosystems and/or human use (USGS 2001). Coastal, shelf, and deep water environments are subject to a variety of processes, interactions, influences, and stresses that determine the quality of the water they contain.

In this chapter, the determinants of, the status of, and the trends in water quality in the Gulf of Mexico are reviewed. This review draws on periodic summaries of national coastal conditions by various federal, state, and local agencies and programs. These summaries are reviewed but the underlying primary data are not reanalyzed. The assessments involved were produced by a large number of expert government personnel and academicians based on a vast amount of data and information from primary sources and peer-reviewed literature. These assessments are based on comparable information that strengthen conclusions and allow for comparisons over time. The synthesized data comes from hundreds of sources including national program reports; water quality reporting at the federal, state, and local levels; locally organized monitoring programs; and published literature. These reports and data collection programs span the 1990s to the mid-2000s and often use differing metrics, indicators, and methods for assessing and rating water quality. The time period considered was based on the date that approaches to assessing water quality were adopted region wide and the date of the most recent, complete assessment. The approximate 20-year time period is also most relevant to defining the present day status and trends in water quality in the northern Gulf of Mexico. Data collected pre-1990 is unlikely to reveal significant additional insights and is difficult to integrate with later assessments due to inconsistencies in the methods and approaches used. The end date of the period of time considered was based on the latest, fully vetted national assessment (USEPA 2012). National assessment reports lag data collection by several years due to the process involved. In addition, assessment and rating tools have evolved over time within programs. While standard approaches were often used, caution was taken when comparing data and assessments across many years and multiple programs, though trends in water quality can be discerned. For ease of reference, the methods used to assess and rate water quality are summarized in Appendix A for most of the reports and monitoring programs included in this summary.

C.H. Ward (ed.), *Habitats and Biota of the Gulf of Mexico: Before the Deepwater Horizon Oil Spill*,
DOI 10.1007/978-1-4939-3447-8_2

2.2 DETERMINANTS AND MEASURES OF WATER QUALITY

Good water quality is a concept that is derived from a suite of characteristics, and therefore has no single definition. Important determinants of water quality in the Gulf of Mexico are physiographic setting and human activities. Measures of water quality include water clarity, degree of eutrophication, and chemical (petroleum and non-petroleum pollutants) and biological (pathogens) contamination. Natural and anthropogenic effects on water quality are dynamic on many scales leading to considerable variability in space and over time. Impacts on water quality by multiple factors can be additive and/or synergistic. The cumulative effect of natural and anthropogenic influences and processes ultimately determines water quality. The type and mix of components used to define water quality is highly site dependent. It is useful to assess water quality by also considering other indicators of environmental condition such as sediment quality, ecosystem health, and sediment, organismal, and beach contamination. In this chapter these other aspects are only considered in the context of conclusions about water quality and are more comprehensively treated within the national assessments.

2.2.1 Physiographic Setting

The geology, morphology, and oceanographic setting of the Gulf of Mexico are first order determinants of water quality. This review restricts itself to the northern Gulf of Mexico stretching from the southern tip of the Florida Keys to the Texas/Mexico border. Runoff from nearly two-thirds of the continental United States empties into the Gulf of Mexico, primarily via the Mississippi River system and its tributaries (NOAA 1985; USEPA 2006). The geomorphology of the Gulf of Mexico coastal region is characterized by flat coastal plains with adjacent marine environments that are subject to high rates of sediment deposition. A major feature of the Gulf of Mexico is estuaries that have formed large deltas at river mouths reflective of high-energy inflows into lower energy offshore environments. Suspended sediment carried by runoff is deposited in shallow coastal waters and redistributed by nearshore currents often forming sand bars and enclosing shallow, saline lagoons that are most common along the Texas coast. The inlets to these lagoons are often narrow and limit the exchange of water with the open Gulf of Mexico. These restrictions of inflow cause lagoon circulation to be primarily wind driven (NOAA 1985; USEPA 2006). Tidal range and influence in shallow coastal plain estuaries of the Gulf Coast is small varying between 0.3 meters (m) (1 foot [ft]) in Louisiana and Texas to 1.1 m (3.6 ft) in Florida (NOAA 1985). Hurricanes are common from June to late November and can have a dramatic effect on water quality by increasing freshwater inflow due to precipitation and saltwater intrusions due to storm surge. Annual rainfall varies from an average of 1.2 m (3.9 ft) in western Florida to 1.4 m (4.6 ft) in Alabama, Mississippi, and Louisiana to 0.6 m (2.0 ft) in south Texas (NOAA 1985; USEPA 2006). The Gulf Coast includes feeding, spawning, and nursery habitats for fish, wildlife, and plant species that support submerged aquatic vegetation communities that stabilize shorelines from erosion, reduce non-point source loadings, improve water clarity, and provide wildlife habitat. Water quality can be influenced by a wide variety of natural processes including atmospheric transport and deposition, erosion of solids and sediments, runoff, and exchanges between surface water and groundwater.

Most estuarine systems in the Gulf of Mexico are located in low-lying watersheds. The Gulf of Mexico region includes the Mississippi River basin as well as small coastal watersheds in Florida (Figure 2.1a). The watershed area to estuarine area ratio exerts a significant influence on water quality, especially in areas adjacent to dense populations of humans. This ratio can be used as an indicator of the influence of watershed-based inputs on the estuary. Estuaries in the

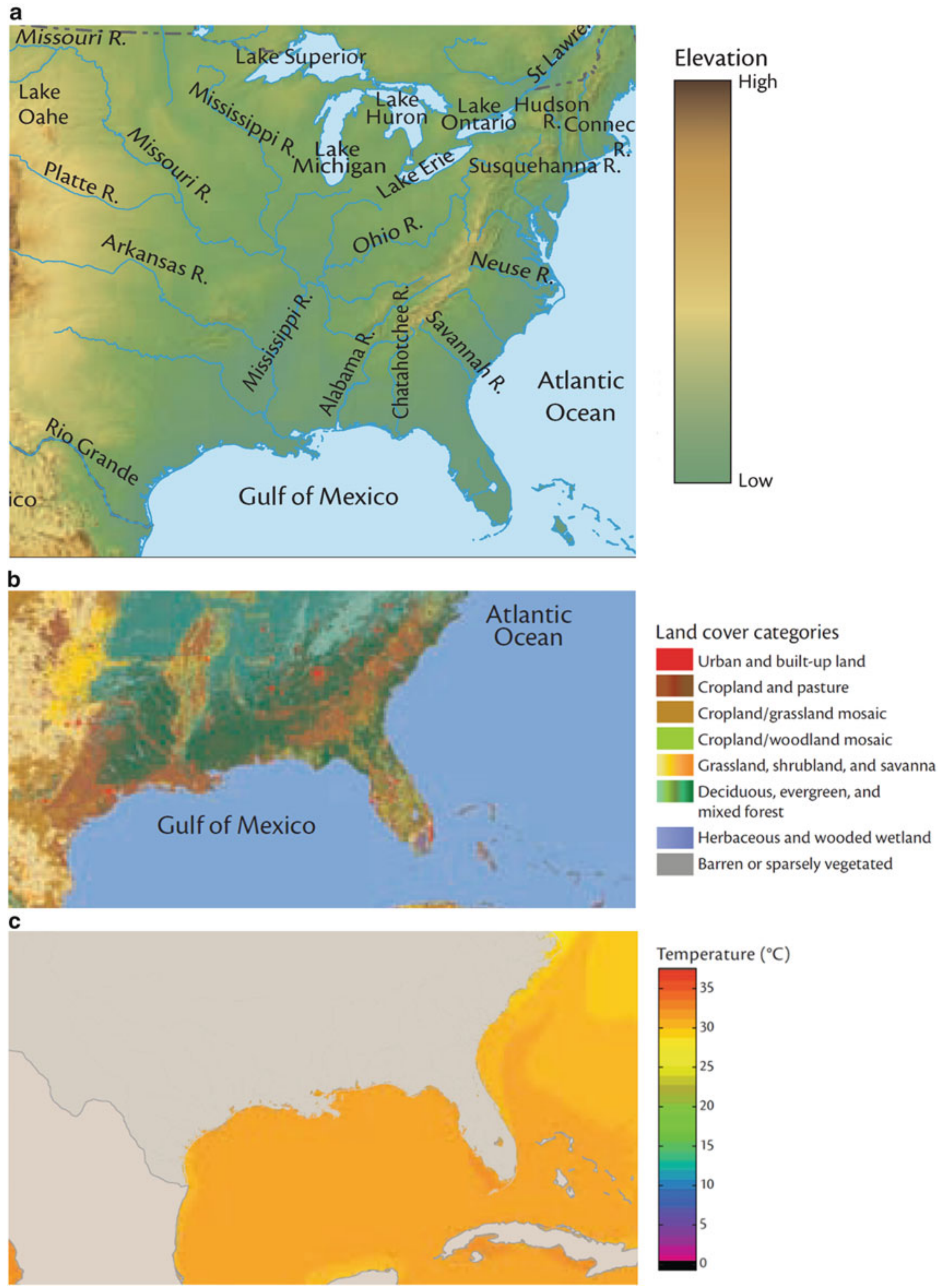

Figure 2.1. (a) Elevation and major rivers of the Gulf of Mexico; (b) land cover categories along the Gulf of Mexico; and (c) sea surface temperature (°C—degree Celsius) in the Gulf of Mexico (modified from Bricker et al. 2007).

Gulf of Mexico have high watershed-to-estuary ratios with input from large watersheds entering small water bodies. Rainfall amounts and patterns also influence the delivery of nutrients to estuaries. Watersheds located in the western Gulf of Mexico are relatively dry with land cover dominated by grassland, shrub land, and savanna (Figure 2.1b). The eastern Gulf of Mexico has a subtropical climate with higher annual rainfall and land covers dominated by croplands and woodlands. Climate along the coast is modulated by ocean temperatures that are warm along the Gulf of Mexico. Annual mean temperatures reflect this modulating influence (Figure 2.1c). The present average number of frost days along the Gulf of Mexico coast is 12 per year.

2.2.2 Human Activities

The Gulf Coast region has been under pressure due to human development for many decades. Studies conclude that the water quality of the majority of estuaries and coastal environments of the Gulf of Mexico are highly influenced by human-related activities (Bricker et al. 2007). Observations of degraded water quality have been largely attributed to dense and increasing human populations in coastal areas (Bricker et al. 2007). Changes in water quality are associated with human activities such as agriculture; residential and urban development; diversion of waterways; coastal construction and shoreline alterations; recreational activities; transport systems; fossil fuel usage; and industrial complexes (e.g., refineries and petrochemical facilities). These activities create the conditions that cause eutrophication, nutrient introductions, and point and non-point source pollutant releases. It is beyond the scope of this paper to exhaustively summarize land usages, the scope and history of human activities, and population trends in the Gulf of Mexico. However, a select set of snapshots are provided as a view of the types of pressures on the Gulf of Mexico that influence the status and trends observed in water quality.

In 2006, the National Estuary Program (NEP) identified major environmental concerns focused in coastal areas (Figure 2.2) (USEPA 2006). Some environmental concerns affect all estuaries and others affect specific locations due to unique climactic, hydrologic, geologic, or geomorphologic conditions and/or the mix of anthropogenic pressures.

In most instances, human influences diminish with distance offshore, so the quality of deep waters overlying the continental shelf/slope and abyss are largely outside the influence of coastal human activities. One notable exception in the Gulf of Mexico is hypoxia on the continental shelf linked to Mississippi River inflows and associated nutrient enrichments. In addition, offshore water quality is subject to pressures from offshore oil and gas exploration and production, shipping, recreational and commercial fishing, and natural oil and gas seepage. Atmospheric transport of various contaminants can be an important pathway for some pollutants to enter the marine environment, and this process can deliver pollutants significant distances offshore in some instances (e.g., mercury from coal-fired power plants).

Population and demographics are closely correlated with the stressors experienced by coastal areas and associated water resources. As an example of increasing anthropogenic pressures, the population of the 48 coastal counties along the Gulf of Mexico increased by more than 133 % from 4.9 million people in 1960 to 11.3 million people in 2000 (Figure 2.3) (U.S. Census Bureau 1991, 2001; USEPA 2006). Population density for these coastal counties was 746 persons per square kilometer (persons/km^2) (1,933 persons per square mile (persons/mi^2) in 2000 with population densities varying from 251 persons/km^2 (651 persons/mi^2) for the Galveston Bay complex to 20 persons/km^2 (53 persons/mi^2) for the Coastal Bend Bays region (U.S. Census Bureau 2001; USEPA 2006).

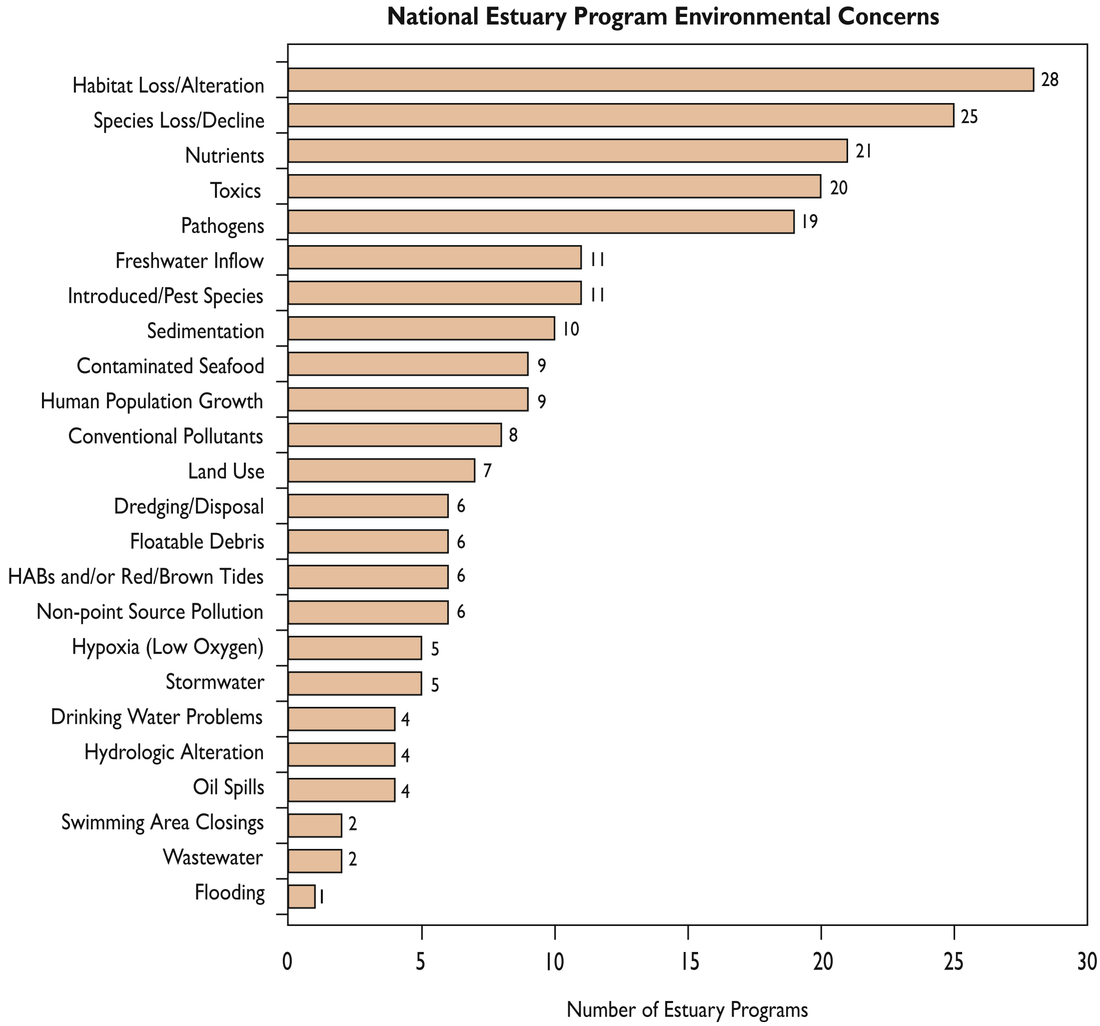

Figure 2.2. Environmental concerns for U.S. estuaries; numbers indicate how many of 28 national estuaries of significance are experiencing a particular concern; HAB—Harmful Algal Blooms (modified from USEPA 2006).

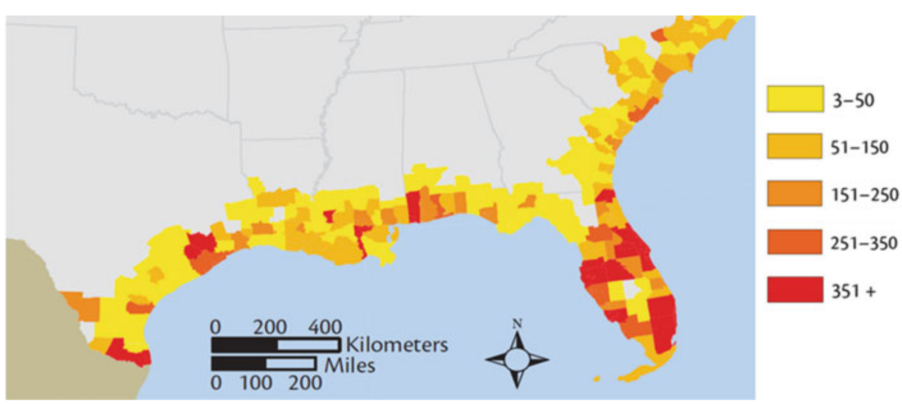

Figure 2.3. Population along the Gulf of Mexico coast in 2003; numerical units are in thousands of persons/mi^2 (modified from Bricker et al. 2007).

The Gulf of Mexico is a focus for commerce and supports considerable and varied recreational activities. In 1999, the Gulf of Mexico Program summarized the major effects humans were having on the Gulf of Mexico (USEPA 1999):

- Texas, Louisiana, and Alabama ranked first, second, and fourth in the nation in 1995 in terms of discharging the greatest amounts of toxic chemicals.
- More than half of the oyster-producing areas along the northern Gulf of Mexico are permanently or conditionally closed. These closure areas are growing as a result of increasing human and domestic animal populations.
- Diversions and consumptive water use for human activities have significantly changed the quantity and timing of freshwater inflows to Gulf of Mexico coastal habitats.
- Louisiana is losing coastal wetlands at the rate of approximately 65 km^2 (25 mi^2) per year.
- Up to 18,000 km^2 (7,000 mi^2) of oxygen deficient (hypoxic) bottom waters have been observed offshore of the Louisiana and upper Texas coasts.

Land use within Gulf of Mexico estuarine watersheds was summarized by the U.S. Environmental Protection Agency (USEPA) in 1999 (USEPA 1999). Gulf of Mexico estuaries were estimated to be approximately 30,000 km^2 (11,600 mi^2) representing 42 % of the total estuarine surface area of the United States excluding Alaska. The Mississippi River drainage area was estimated to be more than 4 million km^2 (1.5 million mi^2), which is more than 55 % of the total area of the conterminous United States. The Gulf of Mexico was receiving an average of 27,473 cubic meters per second (m^3/s) of freshwater inflow daily which was more than 50 % of the daily average for the continental United States. Land use within a watershed determines the materials carried by runoff into adjacent coastal areas. In classifying the land-use categories of the five Gulf States (not the entire watershed), forest and agriculture occupied approximately 58 % of the land area. Forests provide filtration for sediment and nutrients from runoff, stabilize shorelines, and reduce erosion. In the Gulf of Mexico many forests are distant from the shore and are being rapidly replaced by urban and agricultural expansions. Agricultural land included pasture and cropland. Pastureland included grassy areas to raise and feed livestock, and cropland was cultivated for various food products. Other land uses located close to the coastline included wetland habitats (17 %) and urban areas (5 %). While the mix of activities varies with time and place, this snapshot provides an overview of the types of activities that are and will continue to be important for water quality along the northern Gulf of Mexico coastal region.

2.2.3 Water Clarity

Clear waters are valued for aesthetics, recreation, and drinking (USEPA 2008). Water clarity is quantified by the depth of penetration of light (Table 2.1). Light is essential for the health of submerged aquatic vegetation, which serves as food and habitat for other biota. Suspended and dissolved solids that can have natural and anthropogenic sources affect water clarity. Wind and other sources of energy that suspend sediments and particulate matter in water affect water clarity. The amount of dissolved organics and the productivity of phytoplankton affect water clarity and color. Turbid waters have positive as well as negative effects on marine environments. In high-energy environments, turbid waters support healthy and productive ecosystems by supplying the materials that sustain estuarine substrates (i.e., sediments), by being a source of food, and by providing protection for estuarine organisms from predators. In contrast, turbid waters also harm coastal ecosystems by burying benthic

Table 2.1. Criteria for Assessing Water Clarity as an Indicator of Water Quality in Coastal Gulf of Mexico Environments (modified from USEPA 2008)

Area	Good	Fair	Poor
Sites in coastal waters with naturally high turbidity	>10 % light at 1 m	5–10 % light at 1 m	<5 % light at 1 m
Sites in coastal waters with naturally normal turbidity	>20 % light at 1 m	10–20 % light at 1 m	<10 % light at 1 m
Sites in coastal waters that support submerged aquatic vegetation	>40 % light at 1 m	20–40 % light at 1 m	<20 % light at 1 m
Regional assessments criteria of condition as good, fair or poor	Less than 10 % of the coastal area is in poor condition, and more than 50 % of the coastal area is in good condition	10–25 % of the coastal area is in poor condition, and more than 50 % of the coastal area is in combined fair and poor condition	More than 25 % of the coastal area is in poor condition

communities, inhibiting filter feeders, and/or blocking light needed by photosynthetic vegetation. Within an estuary, water clarity can be highly variable over short distances and through time due to tides, storm events, mixing by winds, and changes in incident light. Water clarity is highly variable; it is usually measured based on a ratio of observed clarity in comparison to a reference condition.

One measure of water clarity—turbidity—measures the amount of light that passes through the water over a given distance. Suspended materials include soil inorganic (e.g., clay, silt, and sand) and organic (e.g., bacteria, algae, plankton, and zooplankton) particles. Suspended particles vary in size and affect water clarity and color. Suspended solids/sediments come from non-point sources (e.g., stormwater runoff, stream erosion, agricultural runoff, urban runoff, and leaching of soils) and point sources (i.e., construction projects and industrial or sewage treatment plant discharges). Total suspended solids (TSS) are defined as that material indefinitely suspended in solution but retained on a sieve size of two micrometers (2 μm). Settleable solids refer to material that does not remain suspended or dissolved when water is motionless. Settleable solids may include large particulate matter or insoluble particles. The total inorganic and organic substances dissolved in water are called total dissolved solids (TDS). Dissolved solids are usually defined as material that passes through a sieve size of 2 μm (APHA 1992). TDS is normally only an indicator of water quality for freshwater because saltwater contains dissolved ions that are included in measurements of TDS. The sources of TDS are similar to those for suspended solids. Chemicals commonly dissolved in water include calcium, phosphates, nitrates, sodium, potassium, and chloride. These chemicals are found in various types of runoff from land surfaces and occur as cations, anions, molecules, and/or aggregates. Contaminants that can partially occur in a dissolved state include hydrocarbons, metals, and persistent organic pollutants. Naturally occurring TDS are formed during the weathering of rocks and soils. Processes that affect turbidity in estuaries include resuspension, deposition, and advection of sediment. Tide-dominated estuaries are naturally turbid because strong tidal currents tend to resuspend sediments. Tidal currents can mobilize fine sediments, and turbidity can vary considerably during daily tidal cycles. Trapping and flocculation of sediment at the salinity discontinuity (mixing zone) between freshwater and seawater can cause a turbidity maximum. Criteria have been developed to assess water clarity in the coastal Gulf of Mexico based on light penetration (Table 2.1).

2.2.4 Eutrophication

In 1999, the National Oceanic and Atmospheric Administration (NOAA) reported the results of a national estuarine eutrophication survey recognizing the persistent and pervasive nature of this environmental problem in the nation's coastal regions:

> One of the most prominent barometers of coastal environmental stress is estuarine water quality, particularly with respect to the inputs of nutrients. Coastal and estuarine waters are now among the most heavily fertilized environments in the world. Nutrient sources include point (e.g., wastewater treatment plants) and non-point (e.g., agriculture, lawns, and gardens) discharges. These inputs are known to have direct effects on water quality. For example, in extreme conditions, excess nutrients can stimulate excessive algal blooms that can lead to increased metabolism and turbidity, decreased dissolved oxygen, and changes in community structure and condition described by ecologists as eutrophication. Indirect effects can include impacts to commercial fisheries, recreation, and even public health. (Bricker et al. 1999)

Assessments of eutrophication are based on several of the most utilized measures of water quality: dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), dissolved oxygen, and chlorophyll *a* concentrations (Figure 2.4). Water clarity is also affected by eutrophication, but water clarity is treated separately above in Section 2.2.3.

Nutrients are essential elements that support biological productivity in coastal waters and sustain healthy and functioning ecosystems. Nutrients of particular concern for water quality are those that contain nitrogen and phosphorus. Nutrients from various sources can increase estuarine concentrations above background levels, increasing rates of organic matter synthesis. These nutrient additions can lead to eutrophication and degraded water quality (Figure 2.5).

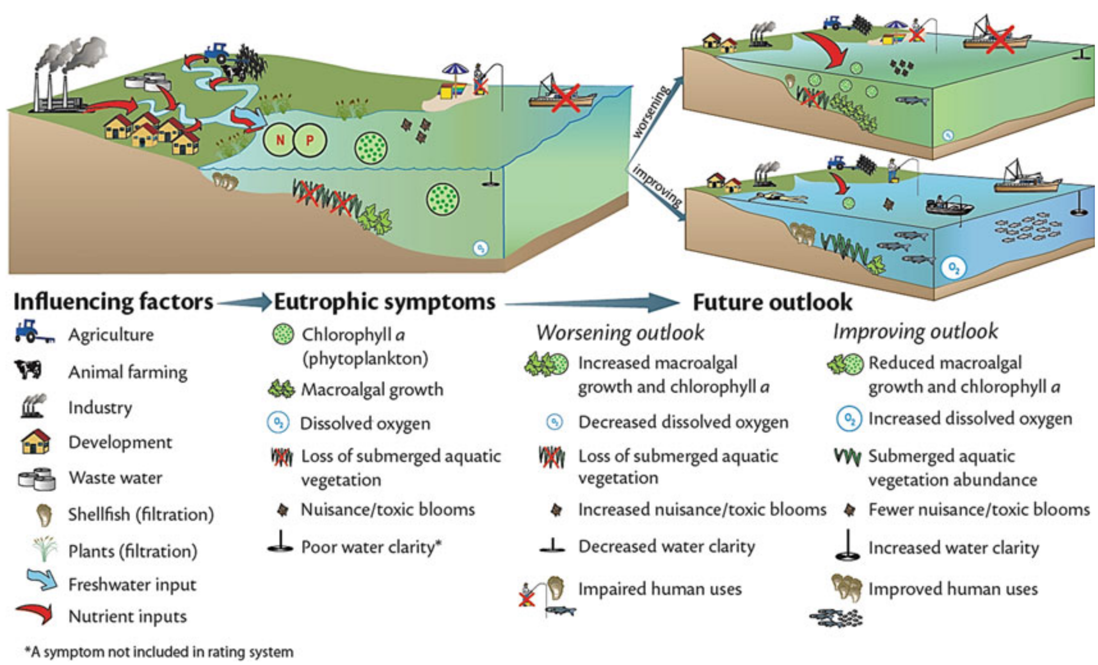

Figure 2.4. Conceptual diagrams of key features, major nutrient sources, and resulting symptoms related to eutrophication in the Gulf of Mexico (modified from Bricker et al. 2007).

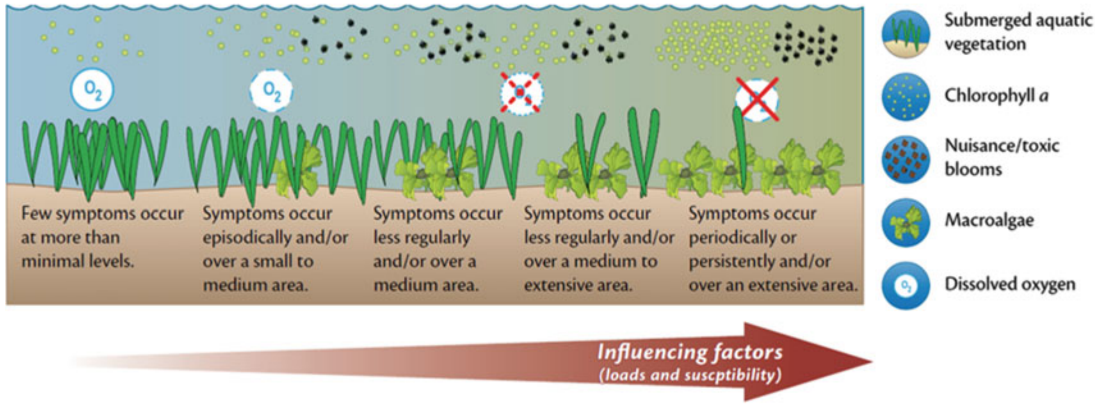

Figure 2.5. Relationship between eutrophication condition, associated trophic symptoms, and influencing factors—nitrogen loads and susceptibility (modified from Bricker et al. 2007).

Excess plant production increases chlorophyll concentrations, decreases water clarity and lowers concentrations of dissolved oxygen due to aerobic decomposition of organic matter. If nutrients are present at concentrations less than needed, the growth and reproduction of organisms is limited. Nutrient additions to aquatic systems occur naturally due to geological weathering and ocean upwelling. In coastal areas, human population growth has increased nutrient inputs many times their natural levels accelerating eutrophication (Figure 2.5). Nutrient increases can threaten biota and lead to impairments of aesthetics, health, fishing opportunities and success, tourism, and real estate values (Figure 2.6).

Nitrogen is usually the primary limiting nutrient for growth of algae in marine waters (Pedersen and Borum 1996). Nitrogen can be found in several different forms in aquatic systems including ammonia (NH_3^+), total nitrogen, nitrites (NO_2-), and most commonly nitrate (NO_3-). Phosphorus in aquatic systems occurs as organic phosphate and inorganic phosphate. Plants use inorganic phosphorus while animals can use either organic or inorganic phosphate to form tissues. Organic and inorganic phosphorus can be dissolved in water or can occur as particulates (e.g., attached to eroded soil). Animals meet their organic phosphorus nutritional requirements by consuming aquatic plants, other animals, and/or decomposing plant and animal detritus. Plants and animals excrete wastes containing both nitrogen and phosphorus.

Nitrogen and phosphorus are released upon the death of an organism by a process termed *remineralization*. Remineralization occurs when bacteria convert organic matter to particulate or dissolved inorganic nitrogen and phosphorus. Inorganic nitrogen and phosphorus in sediments can be resuspended into the water column by bottom dwelling organisms, human activity, diffusion, and/or currents and winds. Remineralized nutrients reenter the food web, once again beginning the cycle. Excess nitrogen and phosphorus are released to aquatic environments by agriculture practices (e.g., application of chemical fertilizer, manure, and organic matter); residential and urban development (e.g., lawn fertilizer, pet wastes, and failing septic systems); and wastewater discharges (e.g., untreated or treated wastewater and sewage) (Figure 2.6). One of the largest inputs of excess nitrogen is the Mississippi River system that delivers excess fertilizer from the heartland of the United States to the Gulf of Mexico (Figure 2.7).

The amount of oxygen dissolved in water is a basic measure of water quality. Organisms in aquatic environments need oxygen to support aerobic respiration. Low oxygen concentrations can reduce aquatic biomass and diversity. Oxygen enters water by diffusion from the

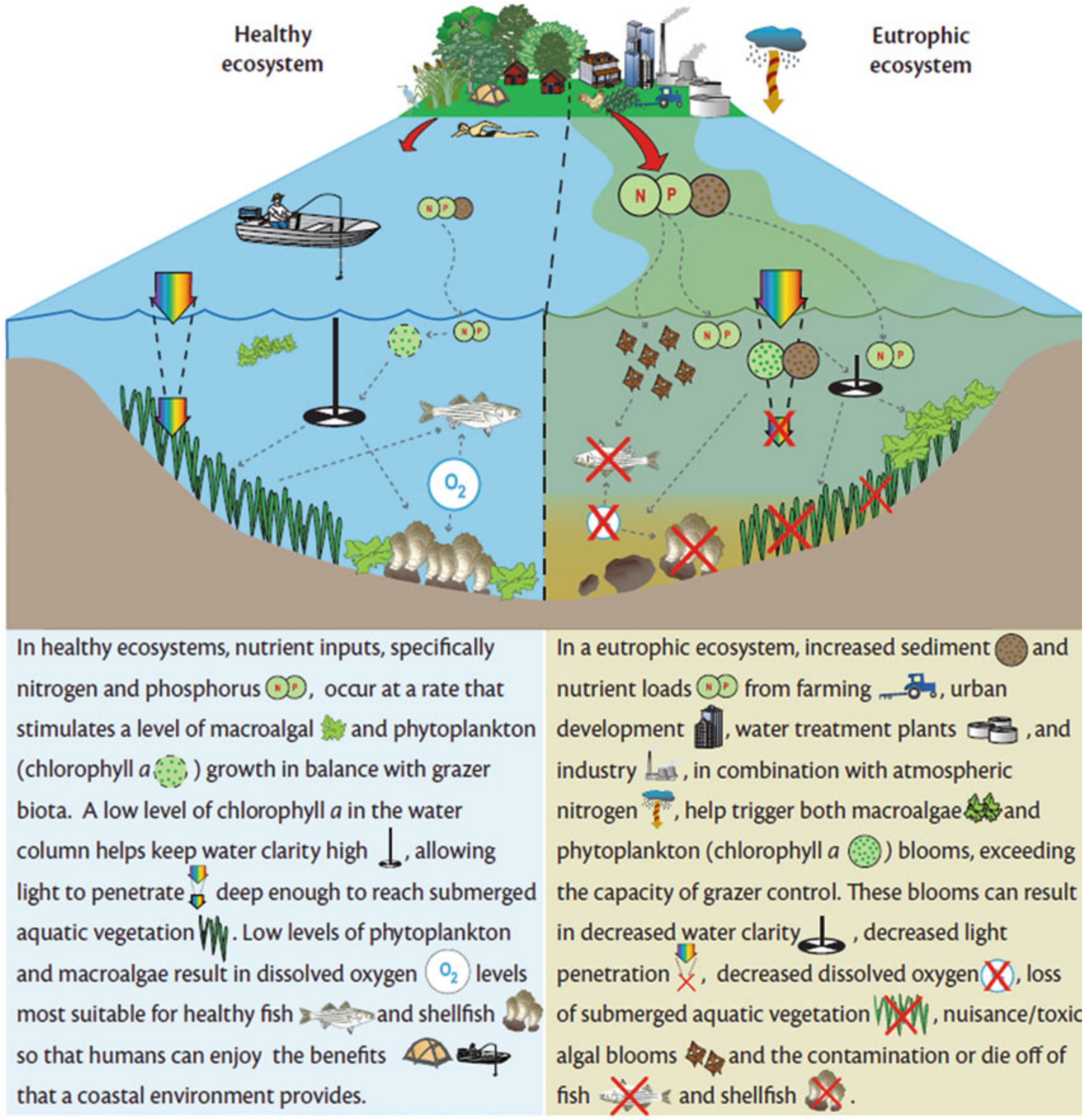

Figure 2.6. Comparison of a healthy system with no or low eutrophication to an unhealthy system exhibiting eutrophic symptoms (modified from Bricker et al. 2007).

atmosphere, by turbulent mixing with the atmosphere, and by release during photosynthesis. Dissolved oxygen is removed from water by diffusion into the overlying atmosphere if concentrations exceed solubility, respiration, and aerobic decomposition (remineralization) of organic matter. Water with less than 1 milligram per liter (mg/L) is anoxic (lethal), and water with less than 5 mg/L of oxygen is suboxic (stressful to most organisms); and water with more than 7 mg/L of oxygen is considered desirable for aquatic life (Table 2.2).

Chlorophyll *a* concentrations are another basic measure of water quality. Chlorophyll *a* indicates the amount of algae (or phytoplankton) growing in a water body. High concentrations of chlorophyll *a* indicate the potential for overproduction of algae resulting in degraded water quality (Table 2.2).

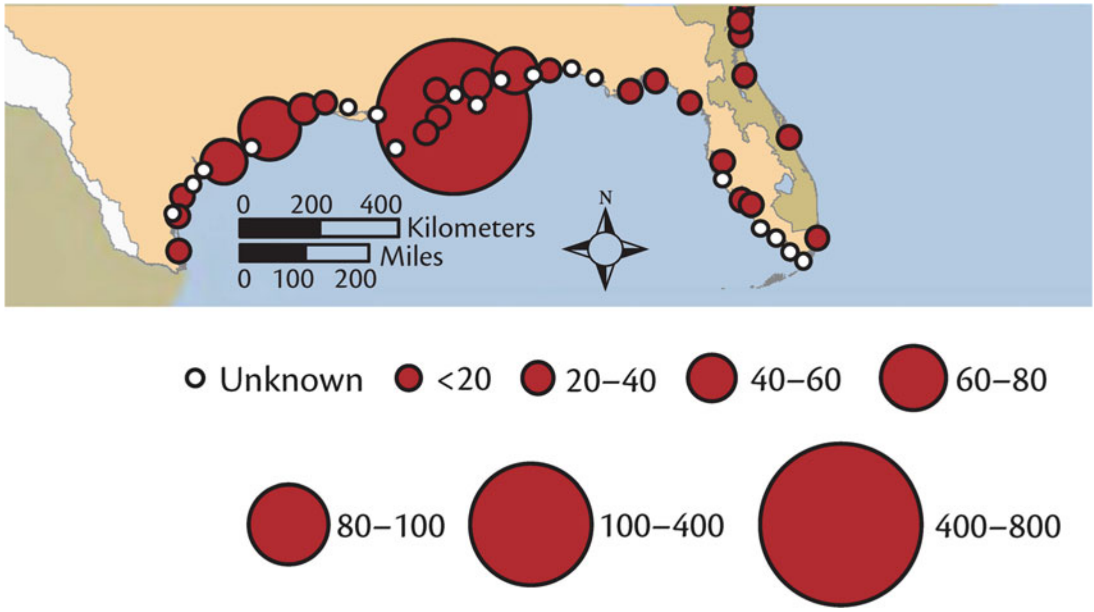

Figure 2.7. Nitrogen loads (×10^6 tons per year) for the Gulf of Mexico. High nitrogen loads correspond with high agricultural activity and the Mississippi River outflow (modified from Bricker et al. 2007).

2.2.5 Chemical Contaminants

Most marine environments are subject to a complex and time-variant mixture of factors that collectively degrade water quality. While contaminant chemicals have the potential to affect water quality, it is usually difficult to unambiguously ascribe degraded water quality to contamination alone (the major exception being excess nutrient releases which can be considered chemical contaminants). There are a few scenarios where chemical contaminants may be the primary cause of degraded water quality such as a major oil spill or locations associated with the manufacture of chemicals (e.g., pesticide manufacturing operations). However, chemical contaminants can, and do, contribute to the degradation of water quality with follow-on effects on associated organisms and ecosystems.

The chemicals that are most often the focus of environmental concern because of known toxicological properties and their wide usage by humans include aromatic hydrocarbons, metals, and persistent organic pollutants. In this review, these chemicals are collectively referred to as *contaminants* (excluding nutrients which are separately considered above). Some contaminants have natural as well as anthropogenic origins. In this review, contaminants are categorized into two major classes: petroleum and non-petroleum (although some non-petroleum chemicals are synthesized from petroleum), and their effects on water quality are separately considered. Non-petroleum contaminants are further subdivided into organic and inorganic contaminants. Each category of chemical contaminants has different sources, environmental fates and effects, toxicities, and potentials to degrade water quality.

Petroleum, including products refined from petroleum, contains a complex mixture of potentially toxic compounds. The class of compounds that accounts for most of the toxicity of petroleum is polycyclic aromatic hydrocarbons (PAHs) (NRC 2003). PAH concentrations are often used as an indicator of petroleum contamination, but other measures, such as oil and grease gravimetrically (by weight) determined as total extractable hydrocarbons or gas

Table 2.2. Criteria for Assessing Dissolved Inorganic Nitrogen, Dissolved Inorganic Phosphorus, Dissolved Oxygen, and Chlorophyll *a* Concentrations as Indicators of Water Quality in Coastal Gulf of Mexico Environments (modified from USEPA 2008)

Indicator	Good	Fair	Poor
Dissolved inorganic nitrogen	<0.1 mg/L	0.1–0.5 mg/L	>0.5 mg/L
Dissolved inorganic phosphorus	<0.01 mg/L	0.01–0.05 mg/L	>0.05 mg/L
Dissolved oxygen	>5 mg/L	2–5 mg/L	<2 mg/L
Chlorophyll *a*	<0.5 μg/L	5–20 μg/L	>20 μg/L
Regional assessment criteria as good, fair, or poor			
Dissolved inorganic nitrogen	Less than 10 % of the coastal area is in poor condition, and more than 50 % of the coastal area is in good condition	10–25 % of the coastal area is in poor condition, and more than 50 % of the coastal area is in combined fair and poor condition	More than 25 % of the coastal area is in poor condition
Dissolved inorganic phosphorus	Less than 10 % of the coastal area is in poor condition, and more than 50 % of the coastal area is in good condition	10–25 % of the coastal area is in poor condition, and more than 50 % of the coastal area is in combined fair and poor condition	More than 25 % of the coastal area is in poor condition.
Dissolved oxygen	Less than 5 % of the coastal area is in poor condition, and more than 50 % of the coastal area is in good condition	5–15 % of the coastal area is in poor condition, and more than 50 % of the coastal area is in combined fair and poor condition	More than 15 % of the coastal area is in poor condition
Chlorophyll *a*	Less than 10 % of the coastal area is in poor condition, and more than 50 % of the coastal area is in good condition	10–20 % of the coastal area is in poor condition, and more than 50 % of the coastal area is in combined fair and poor condition	More than 20 % of the coastal area is in poor condition

mg/L milligram(s) per liter (parts per million (ppm)), *μg/L* microgram(s) per liter (parts per billion (ppb))

chromatographically resolved compounds determined by flame ionization or mass spectroscopy detection, are also used. These methods quantify different portions of petroleum and are subject to different interferences (including the measurement of non-petroleum materials), so results are usually difficult to compare. PAHs are complex mixtures of sometimes hundreds of compounds. Petroleum is released to the environment by intentional and/or unintentional discharges and spills and as byproducts of petroleum usage by humans (NRC 2003). Petroleum is also released to the environment by natural processes such as oil and gas seepage.

Non-petroleum, organic contaminants include polychlorinated biphenyls (PCBs), chlorinated pesticides, and other synthetic chemicals. These chemicals usually, but not always, contain halogens—particularly chlorine and bromine—accounting in part for their toxicity. These chemicals are widely used by humans for various purposes and are ubiquitous in marine environments (see Appendix B for descriptions of common organic contaminants). Non-petroleum, inorganic contaminants include various metals. The most common metals of environmental concern include lead, mercury, arsenic, cadmium, silver, nickel, selenium, chromium, zinc, and copper. These metals are known to have toxicological properties. Organometallic compounds are also included in this subcategory of compounds including tributyltin (used in antifouling paints) and methylmercury (a microbial metabolic derivative of mercury). Metals are released to the environment by human activities including vehicle emissions, industrial processes, improper use or disposal of metallic products, and pesticides (see Appendix C for descriptions of common metal contaminants). Many metals also occur naturally in crustal rocks and minerals. Beyond the contaminants mentioned above, there are also a series of other human-derived chemicals that have the potential to cause environmental degradation including improper disposal of unused pharmaceuticals, household chemicals, and personal hygiene products; fire retardants (brominated compounds); and endocrine-disrupting or mimicking compounds. However, most monitoring programs rarely systematically measure these chemicals in the waters of the northern Gulf of Mexico, so the extent and impact of these chemicals remains largely unknown.

In this chapter, the potential for petroleum contamination to degrade water quality is partially inferred from annual mass loadings of petroleum to the northern Gulf Mexico. Estimates of the inputs of petroleum to the Gulf of Mexico are summarized by the National Research Council's (NRC's) *Oil in the Sea III*: *Inputs*, *Fates*, *and Effects* report (NRC 2003). This report is the most recent comprehensive compilation of petroleum inputs to the northern Gulf of Mexico and is based on data from the 1990s (NRC 2003). The 9-year averages provided are representative of longer-term trends in the region. However, the absolute amounts associated with various sources are expected to vary with time. Mass loading estimates cannot be used to infer petroleum concentrations in environmental matrices such as water but do provide some insight into the origins, geographic distribution, and magnitude of petroleum inputs within limits (Tables 2.3 and 2.4). Within these limitations, mass loadings of petroleum are qualitatively compared and contrasted with observed spatial and temporal patterns in water quality in the northern Gulf of Mexico to determine if any relationship exists.

Due to low solubility in water, contaminant concentrations in water are usually low, challenging even the most sensitive analytical methods. Therefore, most water quality monitoring programs do not routinely measure the concentrations of contaminants in water (except nutrients). However, contaminants may contribute to degraded water quality even though ambient water concentrations are low. Because of their hydrophobic properties, contaminants preferentially accumulate in biological tissues and sediments. Over time organisms exposed to low levels of contaminants in water will continue to accumulate contaminants because contaminant solubility in lipid-rich biological tissues far exceeds their solubility in water. Biological tissue contaminant concentrations can potentially indicate the presence of contaminants in water that may not be detectable by direct analysis. However, there are complications in inferring that contaminants are present in water by their presence in biological tissues. Contaminants can accumulate in organismal tissues via pathways other than uptake from contaminated water. Some organisms ingest contaminated sediments. Other organisms consume contaminated dietary foodstuffs. Some organisms remove contaminants from their systems through depuration and excretion. In many organisms, physiological processes that can detoxify contaminant chemicals are quite advanced, while other organisms have little innate ability to detoxify contaminants. Higher trophic level organisms such as fish consume contaminated organisms, and the levels of contaminants increase by a process termed *biomagnification*. Larger and larger organisms consume greater and greater biomass to support their higher metabolic demands. The organisms themselves, as well as their living foodstuffs, may have

Table 2.3. Concepts Related to the Behavior of Petroleum in the Environment Important to Interpreting Mass Loadings of Petroleum to Marine Environments (modified from NRC 2003)[a]

Process/factor	Definitions/concepts/description/importance
Weathering	A series of changes in physical and chemical properties: • Weathering processes occur at very different rates • Weathering rates are not consistent and are usually highest immediately after release • Weathering processes and rates at which they occur depend more on the type of oil than on environmental conditions • Most weathering processes are highly temperature dependent
The size of the release and the impact on organisms	Loading rates, in units of mass per unit time, are useful for comparing the relative importance of various types of loadings and describing the spatial distribution of loadings • Petroleum is a complex group of mixtures, and each group may contain widely varying relative amounts of hundreds (or more) compounds • Many of the compounds are apparently benign. Many others, such as some types of PAH, are known to cause toxic effects in some marine organisms • Predicting the environmental response to a specific release of a known quantity of a refined petroleum product (which contains far fewer compounds than crude oil) requires site-specific information about the nature of the receiving water body • Loading and impact are distinct and it is not possible to directly assess environmental damage from petroleum hydrocarbon mass loading rates • Effects tend to reflect the amount of toxic hydrocarbon compounds reaching a marine organism and the differing susceptibility of various organisms, populations, and ecosystems to the effects of these hydrocarbons • Effects tend to reflect the amount of toxic hydrocarbon compounds reaching a marine organism and the differing susceptibility of various organisms, populations, and ecosystems to the effects of these hydrocarbons • Ecotoxicological responses are driven by the dose of petroleum hydrocarbons available to an organism, not the amount of petroleum released into the environment • Dose is rarely directly proportional to the amount released because of the complex environmental processes acting on the released petroleum • The type of petroleum released and the susceptibility of the target organisms must both be considered • It is often difficult to reach consensus on the magnitude and duration of environmental effects

(*continued*)

Table 2.3 (continued)

Process/factor	Definitions/concepts/description/importance
Bioavailability	The amount of petroleum made available to an organism through various environmental processes (whether for ingestion or absorption) is referred to as being biologically available, or simply, bioavailable • The release of equal amounts of the same substance at different times or locations may have dramatically different environmental impacts • Bioavailability can describe the net result of physical, chemical, and biological processes that moderate the transport of hydrocarbon compounds from their release points to the target organisms • Processes acting on petroleum as it moves from the release point to the marine organism can alter the chemical composition of the petroleum mixture, which in turn likely alters the toxicity by selectively enriching or depleting toxic components • Physical weathering processes may encapsulate some or all of the petroleum in forms that are less available to organisms such as tar balls • Physiological and behavioral processes moderate the movement of petroleum from the surrounding environment into marine organisms • Individual petroleum components pass into organisms at different rates depending on their physical and chemical properties • Organisms respond to hydrocarbons in their surroundings and moderate or accentuate exposure • Once the hydrocarbons are in the organisms, there is a wide variation in the types and magnitudes of physiological responses. Many organisms metabolize and excrete hydrocarbons creating more toxic intermediates

[a]These concepts apply most directly to spilled petroleum; however, the general principles apply to all petroleum once released to the environment regardless of source

Table 2.4. Processes that Move Petroleum Hydrocarbons Away from the Point of Origin (modified from NRC 2003)[a]

Input type	Persistence	Evaporation	Emulsification	Dissolution	Oxidation	Horizontal transport or movement	Vertical transport or movement	Sedimentation	Shoreline stranding	Tar balls
Seeps	Years	H	M	M	M	H	M	M	H	H
Spills										
• Gasoline	Days	H	NR	M	L	L	L	NR	NR	NR
• Light distillates	Days	M	L/L	H	L	M	H	L	L	NR
• Crudes	Months	M	M	M	M	M	M	M	H	M
• Heavy distillates	Years	L	M	L	L	H	L	H	H	H
Produced water	Days	M	NR	M	M	L	L	L	L	NR
Vessel operation	Months	M	L	M	L	M	L	L	L	M
Two-stroke engines	Days	H	NR	M	L	L	L	L/NR	NR	NR
Atmospheric	Days	H	NR	M	M	H	NR/NR	L	NR	NR
Land-based	U	M	L	L	L	M	M	M	NR	U

Note: *H* high; *M* moderate; *L* low; *NR* not relevant; *U* unknown

[a]Each input is ranked using a scale of high, medium, and low that indicates the relative importance of each process. The table is intended only to convey variability and is based on many assumptions providing a general idea of the relative importance of these processes. The importance of a particular process will depend on the details of the spill event or release. These concepts apply most directly to spilled petroleum. "The chemical and physical character of crude oils or refined products greatly influences how these compounds behave in the environment as well as the degree and duration of the environmental effects of their release" (NRC 2003)

migrated from distant locations or roamed over great distances. Mobile marine organisms can range over quite large distances and tissue contaminant concentrations reflect what may be a complex history of dosages, exposures, and excretions. All of these factors are highly variable from one species to the next. Contaminant concentrations in organism tissues are the end product of these complex physiological processes and interactions with the environments they live in, confounding the attribution of tissue contaminant sources to specific water bodies.

While recognizing the limitations on interpretations of the data, contaminant concentrations in biological tissues and sediments can provide a qualitative indication that contaminants may be contributing to degraded water quality. A comprehensive review of contaminants in biological tissues in the northern Gulf of Mexico is beyond the scope of this review; however, limited considerations of data on fish consumption advisories are used to identify which chemicals are of greatest concern. The geographic distribution of advisories can pinpoint contaminant hot spots and be compared with the distribution of degraded water quality to identify co-occurrences, but cause and effect is difficult to infer for the reasons identified. Sentinel, sessile organisms, such as filter-feeding bivalves (oysters and mussels), filter and accumulate particles from large volumes of water acting as time integrators of exposure to contaminants in water. Contaminant concentrations in the tissues of these organisms are good indicators of local contamination and can be used to infer possible contaminant-related degraded water quality. Oyster tissue contaminant distributions for the northern Gulf of Mexico are reported and reviewed elsewhere (Kimbrough et al. 2008). The distribution and types of contaminants in sediments can also be used to infer possible contaminant-related degraded water quality. Distributions and origins of the common contaminants in sediments of the northern Gulf of Mexico are reported elsewhere (this volume, Chapter 4).

2.2.6 Water Quality Impairment and Biological Contaminants

Water quality impairment assessments synthesize diverse sets of information to describe the overall condition of marine waters. These assessments indicate the status of water quality and are used to inform the public about risks associated with various uses of marine waters. Assessments of the presence of biological contamination (pathogens) in waters and assessments of chemical contaminants in organisms consumed by the public can provide indications of possible water quality degradation. This chapter reviews the methods used to detect and report the presence of biological contaminants and the translation of these and other data into assessments of how well waters are supporting designated uses, including the criteria for beach closings. These summaries are from documents referenced in the assessments used in this review, and it should be noted that guidance criteria are under continuous review and may have been revised subsequent to the issuing of these assessment reports.

States report water quality assessment information and water quality impairments under Sections 305(b) and 303(d) of the Clean Water Act. These assessments compare field data to state water quality standards (USEPA 2001). Water quality standards include narrative and numerical criteria that are used to judge if water bodies are capable of supporting specific, designated uses without undue risk to public health. These criteria set specific goals that need to be met to prevent degradation of water quality. The criteria are used to evaluate whether the designated uses of water bodies are supported as follows:

- Fully supporting: These waters meet applicable water quality standards, both criteria and designated use.
- Threatened: These waters currently meet water quality standards, but states are concerned they may degrade in the future.

- Partially supporting: These waters meet quality standards most of the time, but exhibit occasional exceedances.
- Not supporting: These waters do not meet water quality standards.

The data is then integrated and compared to established criteria to ascertain if designated uses can be supported with acceptable risk to public health. Categories of water use include aquatic life support; drinking water supply; recreation activities such as swimming, fishing, and boating; and fish and shellfish consumption by humans (USEPA 2001). A water body classified as partially supporting or not supporting its usages is considered impaired. Each state monitors water quality parameters differently, so generalities about condition are often difficult to make based on these data alone. States also issue consumption advisories to inform the public of elevated concentrations of chemical contaminants detected in local fish and shellfish tissues.

Public health may be at risk due to polluted bathing beaches. USEPA established the Beaches Environmental Assessment, Closure, and Health (BEACH) Program and the Program Tracking, Advisories, Water Quality Standards, and Nutrients (PRAWN) to better define the extent of beach contamination in the United States (USEPA 2001, 2008). A few states have comprehensive beach monitoring programs while others have only limited or no beach monitoring programs, making comprehensive assessments of the problem in a region like the northern Gulf of Mexico difficult. However, beach water contamination, particularly by pathogens, is considered to be a persistent problem based on the number of beach closings and swimming advisories issued each year (USEPA 2003a, b). The integration of these data into assessments of impairment provide an indication of water quality issues and assist in identifying possible causative agents that may require regulatory action.

Pathogens can have detrimental effects on water quality. Biological contaminants are introduced to receiving waters by a variety of processes. Fecal bacteria indicate the possible presence of pathogens in water and the risk of humans contracting diseases from the ingestion of contaminated surface water or raw shellfish (USEPA 2003b). Contact with contaminated water can lead to ear or skin infections, and inhalation of pathogen-contaminated water can cause respiratory diseases. These infections and diseases are due to exposure to bacteria, viruses, protozoans, fungi, and/or parasites that live in the gastrointestinal tract of humans and the feces of warm-blooded animals (USEPA 2003b). Concentrations of fecal bacteria, including fecal coliforms, enterococci, and *Escherichia coli* in water are used to indicate fecal contamination (USEPA 2003b). Enterococci and *E. coli* have been shown to correlate with outbreaks of disease, and USEPA recommends them as indicators of biological contamination (USEPA 2003b). Sources of pathogenic organisms include malfunctioning septic systems, overboard discharges of untreated sewage from boats, sewer overflows, improperly stored/used animal manure, pet wastes, and improperly working waste treatment facilities. *E. coli* counts often increase after storm events such as heavy thundershowers or continuous rain. USEPA recommends various bacteriological assay methods to detect indicator pathogens. USEPA bacteriological criterion for restricting bathing in recreational marine water, based on no less than five samples equally spaced over a 30-day period, is that the geometric mean of the enterococci densities should not exceed 35 per 100 milliliters (mL) of water. Because states often adopt their own methodologies and criteria for assessing biological contamination of waters and issuing advisories, comparisons across monitoring programs should be made with caution. For this review, a limited number of the reports of beach closings and the reasons for these closings are provided as an indication of degraded water quality; however, it is not an exhaustive treatment of all available data for the northern Gulf of Mexico which is reviewed elsewhere.

2.3 COASTAL WATER QUALITY

Based on the importance of coastal resources, a coordinated effort to monitor their condition has been in place since the early 1990s in the United States (Bricker et al. 1999; USEPA 2001, 2004, 2008, 2012). One of the first comprehensive, national assessments of estuarine eutrophication was NOAA's *National Estuarine Eutrophication Assessment* in 1999 (Bricker et al. 1999). This was followed in subsequent years by National Coastal Condition Reports that "…describe and summarize the ecological and environmental conditions in U.S. coastal water and highlight exemplary…programs that assess coastal ecological and water quality conditions." The USEPA Office of Wetlands, Oceans and Watersheds' Coastal Programs created these reports to provide a "comprehensive picture of the health of the nation's coastal waters." The reports are based on data collected from a variety of sources coordinated by USEPA, NOAA, the U.S. Geological Survey (USGS), U.S. Fisheries and Wildlife Service (USFWS), and coastal states. One aspect of these national assessments is a region-by-region consideration of water quality. To describe water quality in the Gulf of Mexico, the regional trends in these reports are summarized as well as a discussion of site-specific monitoring results. The reviews of regional assessments are followed by summaries of a series of state-of-the-bay reports that highlight water quality on a finer spatial scale. These are summaries and not a reanalysis of primary, underlying data.

2.3.1 NOAA's Estuarine Eutrophication Assessment (1999)

In 1999, NOAA's National Estuarine Eutrophication Assessment provided the first comprehensive assessment of water quality in the northern Gulf of Mexico (Bricker et al. 1999). The assessment was based primarily on the results of a national survey conducted by NOAA from 1992 to 1997 supplemented by information on nutrient inputs, population projections, and land use from a variety of sources. This assessment catalyzed future USEPA National Coastal Condition Reports. The assessment was conducted at a workshop of experts that participated in a nationwide survey. The report is described as presenting "… the results of a comprehensive National Assessment to address the problem of estuarine eutrophication. The assessment includes evaluations of eutrophic conditions, human influence, impaired estuarine uses, future conditions, data gaps and research needs, and recommendations for a national strategy to respond to the problem…" (Bricker et al. 1999). Eutrophication "…refers to a process in which the addition of nutrients to water bodies stimulates algal growth. In recent decades, human activities have greatly accelerated nutrient inputs, causing the excessive growth of algae and leading to degraded water quality and associated impairments of estuarine resources for human (and ecological) use…" (Bricker et al. 1999).

The report provided regional assessments including the northern Gulf of Mexico. The assessment concluded that "…the expression of high eutrophic conditions is extensive, and human influence is substantial, in the Gulf of Mexico region. Although there is a great diversity of estuary types, common characteristics, such as low tidal flushing, warm water, and long algal growing seasons, create conditions that make many of the region's estuaries susceptible to eutrophic problems. The most significant symptoms in the overall expression of eutrophic conditions are low dissolved oxygen and loss of submerged aquatic vegetation. Impaired resource uses are evident in many, but not all, of the affected systems. Conditions are expected to worsen in more than half of the estuaries by 2020…" (see Figure 2.8).

Of the 38 Gulf of Mexico estuaries and the Mississippi River Plume, 20 estuaries exhibited high levels of at least one of the symptoms of eutrophication. Chlorophyll *a* concentrations were high in 12 estuaries mainly on the coasts of western Florida, Louisiana, and lower Texas.

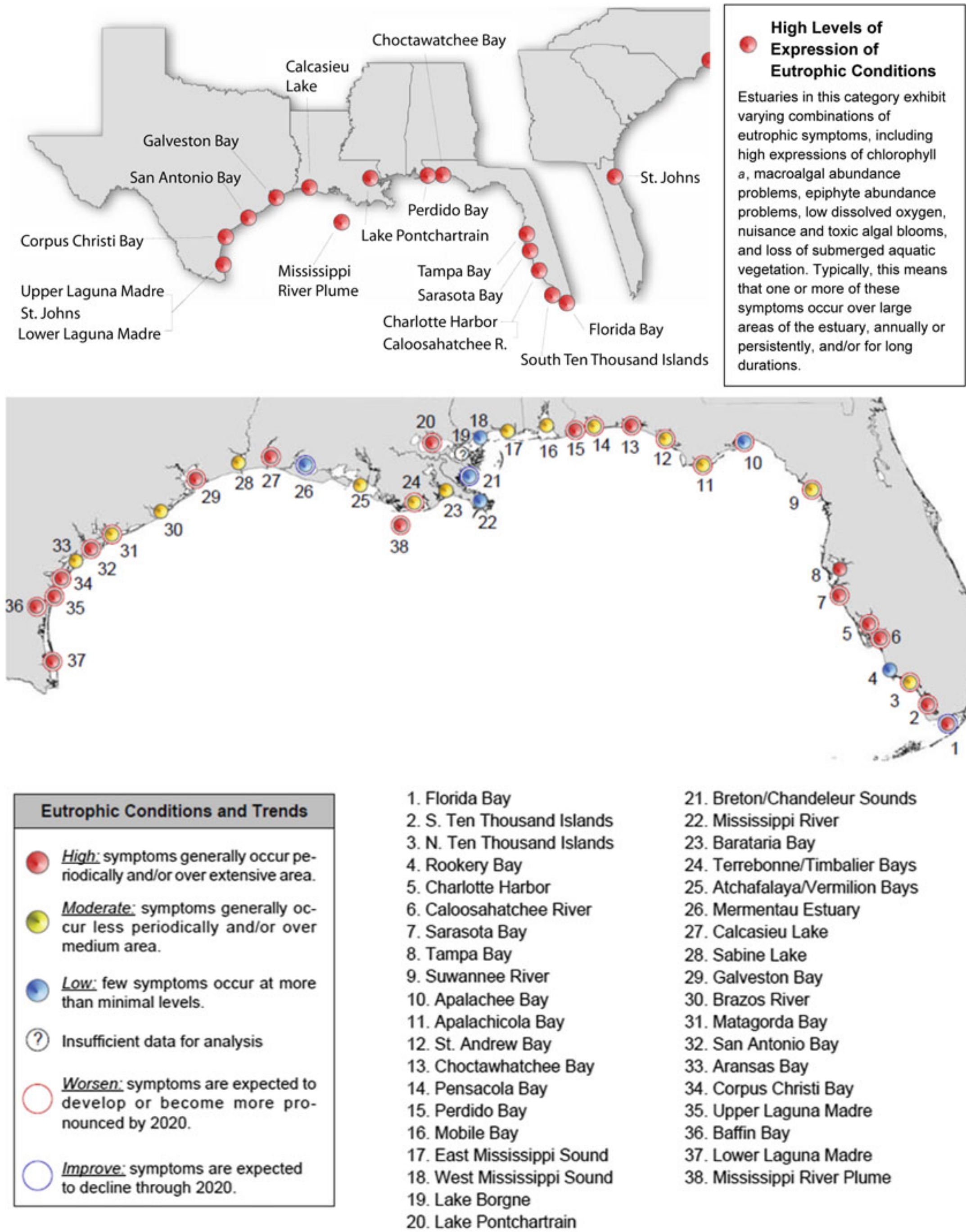

Figure 2.8. Level of expression of eutrophic conditions in the Gulf of Mexico and future trends (modified from Bricker et al. 1999).

Epiphytes were moderate to high in eight estuaries. Macroalgal abundance was moderate to high in seven estuaries. Low dissolved oxygen concentrations were observed in four estuaries along the Florida coast and in the Mississippi River Plume. Submerged aquatic vegetation loss was observed in 28 estuaries, and eight were considered to have high levels of loss along the Florida, western Louisiana, and the lower Texas coasts.

High eutrophic conditions were expressed as loss of submerged aquatic vegetation, increased turbidity associated with high concentrations of chlorophyll *a*, and low levels of dissolved oxygen. Moderate to high levels of nuisance/toxic algal blooms and epiphyte abundance were observed as well. It was noted that conditions seemed to be improving due to better management of point and non-point nutrient sources at some locations. The authors concluded that the Gulf of Mexico was well studied and the data synthesis robust (Bricker et al. 1999). It was also concluded that human influence was high in more than half of the estuaries studied and that this was linked with high expressions of eutrophication. Those areas considered to be most influenced by humans included the Mississippi River Plume, Lake Pontchartrain, Upper and Lower Laguna Madre, and Baffin Bay. Estuaries with lower levels of human influence were Rookery Bay, the Suwannee River, Apalachee Bay, and Breton/Chandeleur Sounds (Figure 2.8) (Bricker et al. 1999).

The factors that had greatest influence on expressions of eutrophication in the Gulf of Mexico were low tidal energy, low flushing rates with increased nutrient inputs, and low dissolved oxygen levels generally due to warm waters and long growing seasons. Nitrogen inputs were considered moderate. Bricker et al. (1999) conclude that impaired uses were difficult to define as being directly related to eutrophication but results suggest that the most impaired uses were recreational and commercial fishing, shellfishing, and loss of submerged aquatic vegetation. Of the 38 estuaries, 23 were predicted to develop worsening conditions during the following 20 years, and six estuaries were judged to be at high risk of worsening eutrophication in the future including the Mississippi River Plume, Lake Pontchartrain, Corpus Christi Bay, Upper and Lower Laguna Madre, and Baffin Bay. Three estuaries were judged to have the potential to decrease eutrophic symptoms in the future, including Florida Bay, Breton and Chandeleur Sounds, and Mermentau Estuary.

2.3.2 USEPA's National Coastal Condition Reports I (2001) and II (2004)

The need for regular assessments of coastal conditions to identify problem areas and judge long-term trends to inform management and regulatory decisions was highlighted by the NOAA eutrophication survey (Bricker et al. 1999). The first National Coastal Condition Report was issued in 2001 based on information collected from 1990 to 1997 (USEPA 2001) and the second was issued in 2004 based on monitoring data collected from 1997 to 2000 (USEPA 2004). These reports concluded that the overall condition of Gulf of Mexico coastal waters was fair to poor (Figure 2.9).

The USEPA Environmental Monitoring and Assessment Program (EMAP) collected environmental stressor and response data from 1991 to 1995 at 500 locations from Florida Bay, Florida, to Laguna Madre, Texas. The conclusions of EMAP were similar to those of NOAA (USEPA 1999; Bricker et al. 1999), that is, eutrophication was one of the most critical problems facing northern Gulf of Mexico ecosystems. EMAP concluded that excess nitrogen enters Gulf of Mexico estuaries via fertilizer runoff from agricultural and residential land, animal manure, and atmospheric deposition. In addition, the region has the highest number of wastewater treatment plants and the most land devoted to agriculture with the most applied fertilizer in the United States. Many Gulf of Mexico estuaries showed evidence of pre-eutrophic or eutrophic conditions. Four indicators of nutrient enrichment were used to assess the overall nutrient status of estuaries: the NOAA Estuarine Eutrophication Survey (Bricker et al. 1999), state 305(b) assessment of nitrogen level, state 305(b) assessment of chlorophyll levels, and the Rabalais et al. (1992) evaluation of nutrient increases. Nutrient problems ranged from minimal in

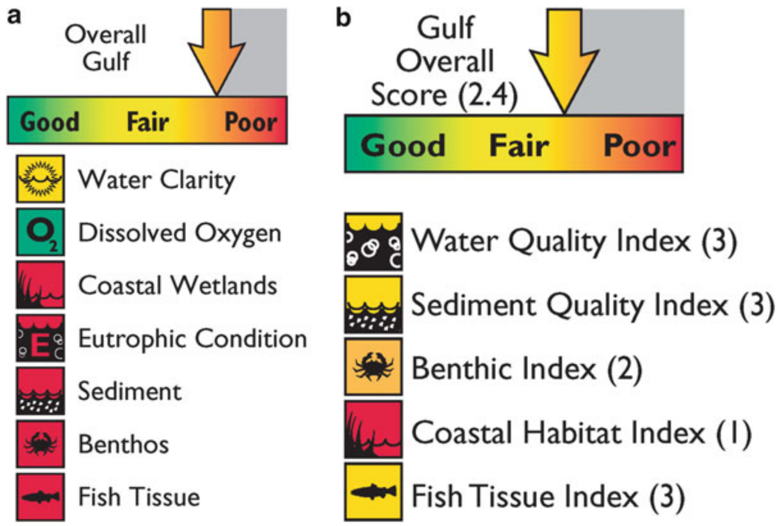

Figure 2.9. (a) Overall condition of Gulf of Mexico coastal resources was rated fair to poor in 2001 (modified from USEPA 2001) and (b) 2004 (modified from USEPA 2004).

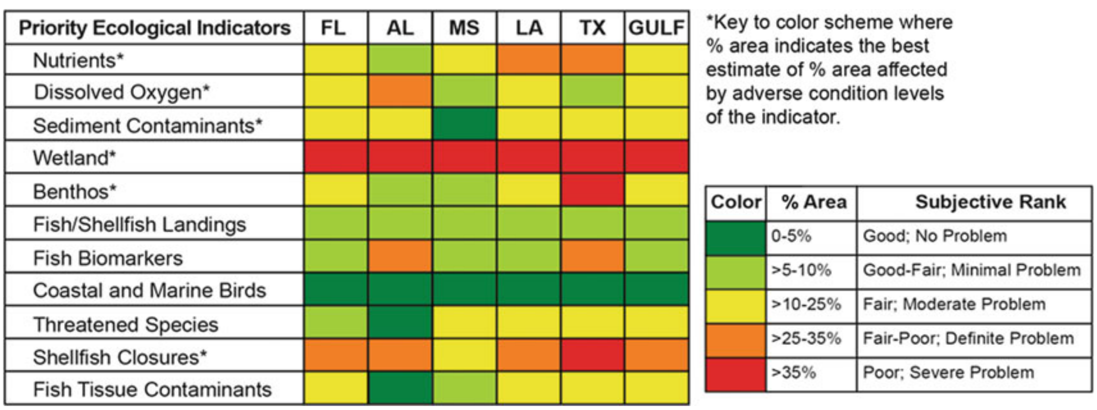

Figure 2.10. Estimates of the status of ecological conditions along the northern Gulf of Mexico (modified from USEPA 1999).

Alabama to definite problems in Louisiana and Texas with overall moderate problems throughout the northern Gulf of Mexico. Low dissolved oxygen concentrations in estuaries were attributed to stratification, metabolism, seasonal storm events, and depth/tide regimes. Low dissolved oxygen was often exacerbated by anthropogenic nutrient enrichment, habitat modifications, and channelization. Using EMAP and NOAA data and the Rabalais et al. (1992) assessment of oxygen depletion, Gulf of Mexico estuaries were ranked as fair overall with most estuaries east of the Mississippi River exhibiting persistent low dissolved oxygen. A USEPA report card representing the best estimate of ecological condition was produced (Figure 2.10). For the overall Gulf of Mexico, 8 of 11 indicators were ranked as fair to poor. Estuaries on the Florida coast had fewer problems than other Gulf States. Alabama coasts rated good to fair for most of the indicators with problems indicated by low dissolved oxygen concentrations. Mississippi rated good to fair for all indicators except wetland loss. Louisiana and Texas estuaries exhibited problems associated with excess nutrients. Estuaries in the northern Gulf of Mexico had significant but variable environmental problems. The report

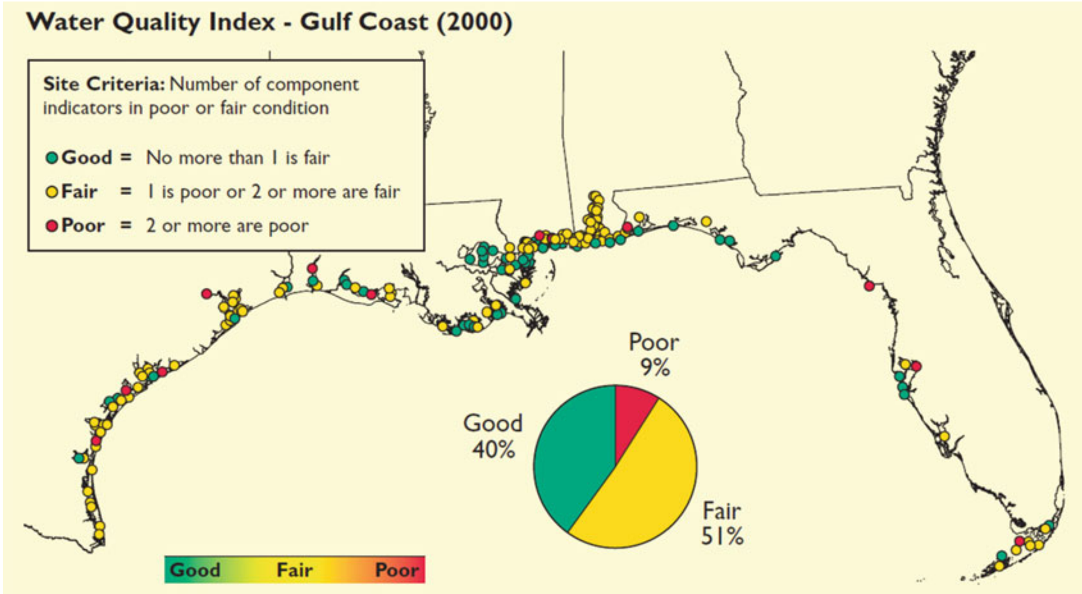

Figure 2.11. Water quality index data for northern Gulf of Mexico estuaries from 1996–2000 (modified from USEPA 2004).

concluded that there had been some improvement in the condition of estuaries since the Clean Water Act was passed, as indicated by the relatively moderate problems with water quality indicators such as nutrients and dissolved oxygen (USEPA 1999).

The assessment process was revised and the indices used to determine coastal condition were redefined; direct comparisons with previous assessments should be made with caution. From 1996 to 2000, Gulf of Mexico estuaries ranked poor for eutrophic condition with 38 % of the estuarine area having a high expression of eutrophication (Bricker et al. 1999). Estuaries with poor water quality conditions were found in all five states but the contributing factors were different. The water quality index used in 2004 (based on five indicators: nitrogen, phosphorus, chlorophyll *a*, water clarity, and dissolved oxygen) showed that 40 % of the estuaries rated good, 51 % fair, and 9 % poor (Figure 2.11).

Water clarity in Gulf Coast estuaries was judged to be fair in the 2001 assessment (USEPA 2001). Water clarity was estimated by the penetration of light through the water column. For 22 % of the waters in Gulf of Mexico estuaries, less than 10 % of surface light penetrated to a depth of 1 m (3.3 ft) (Figure 2.12a). In the 2004 assessment, Texas and Louisiana estuaries had poor water clarity (Figure 2.12b) (USEPA 2004) while overall water clarity in Gulf of Mexico estuaries was again judged to be fair. In the 2001 assessment, dissolved oxygen conditions in Gulf of Mexico estuaries were generally good except in a few highly eutrophic regions. EMAP estimates for Gulf of Mexico estuaries concluded that about 4 % of the bottom waters in Gulf of Mexico estuaries had hypoxic conditions or low dissolved oxygen concentrations (less than 2 parts per million [ppm]) on a continuing basis in the late summer (Figure 2.13a).

Affected areas included Chandeleur and Breton Sounds in Louisiana, some shoreline regions of Lake Pontchartrain, northern Florida Bay, and smaller estuaries associated with Galveston Bay, Mobile Bay, Mississippi Sound, and the Florida panhandle. In the 2004 assessment, dissolved oxygen conditions in northern Gulf of Mexico estuaries were assessed to be good. Less than 1 % of the bottom waters exhibited hypoxia (less than 2 mg/L dissolved oxygen) in the late summer (Figure 2.13b). Affected areas included Mobile Bay, Alabama,

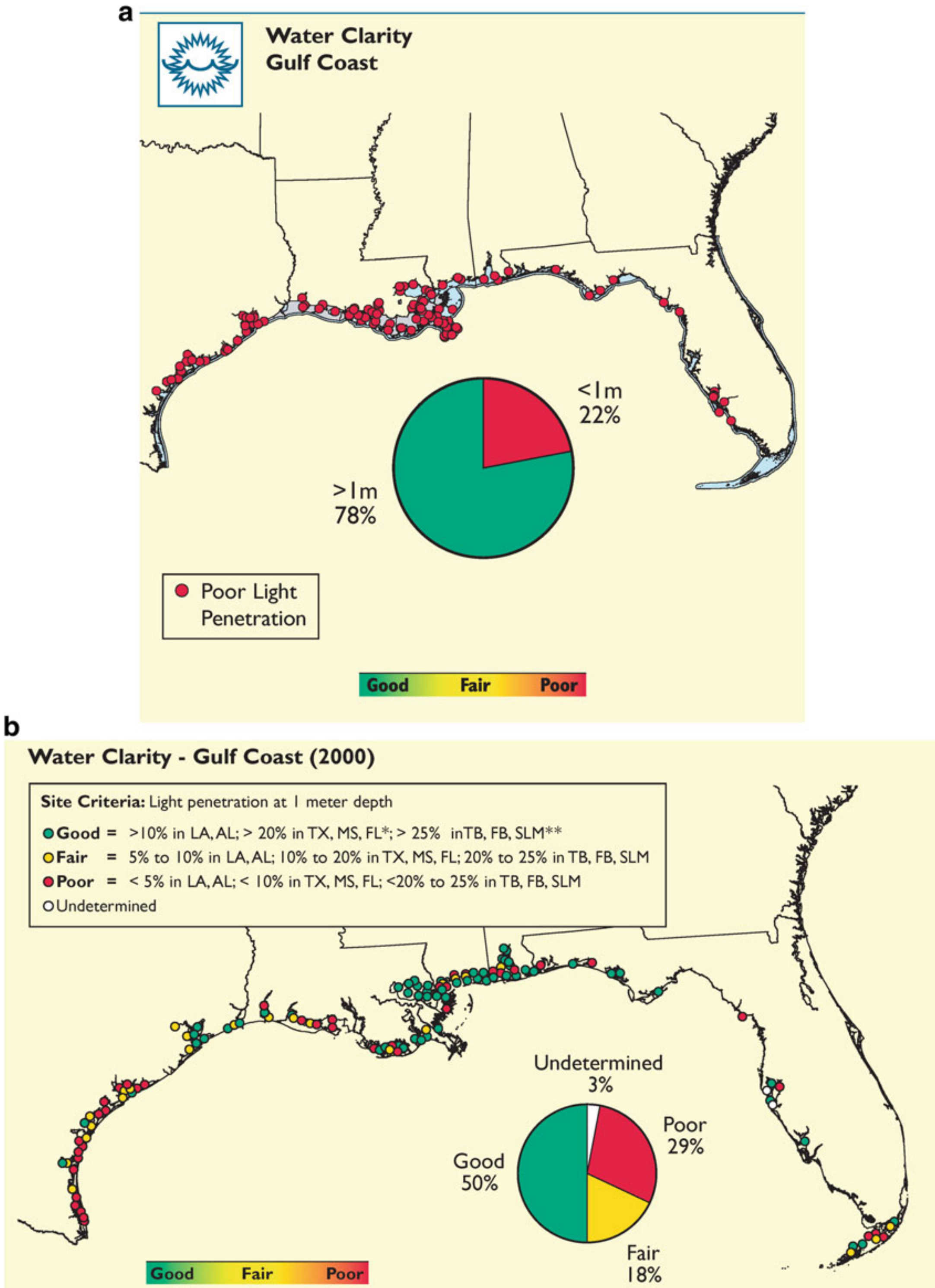

Figure 2.12. (a) Light penetration and locations for sites with less than 10 % light penetration (modified from USEPA 2001) and (b) water clarity for Gulf of Mexico estuaries (*FL = Florida estuaries except Tampa Bay [TB] and Florida Bay [FB], **SLM = Southern Laguna Madre (modified from USEPA 2004).

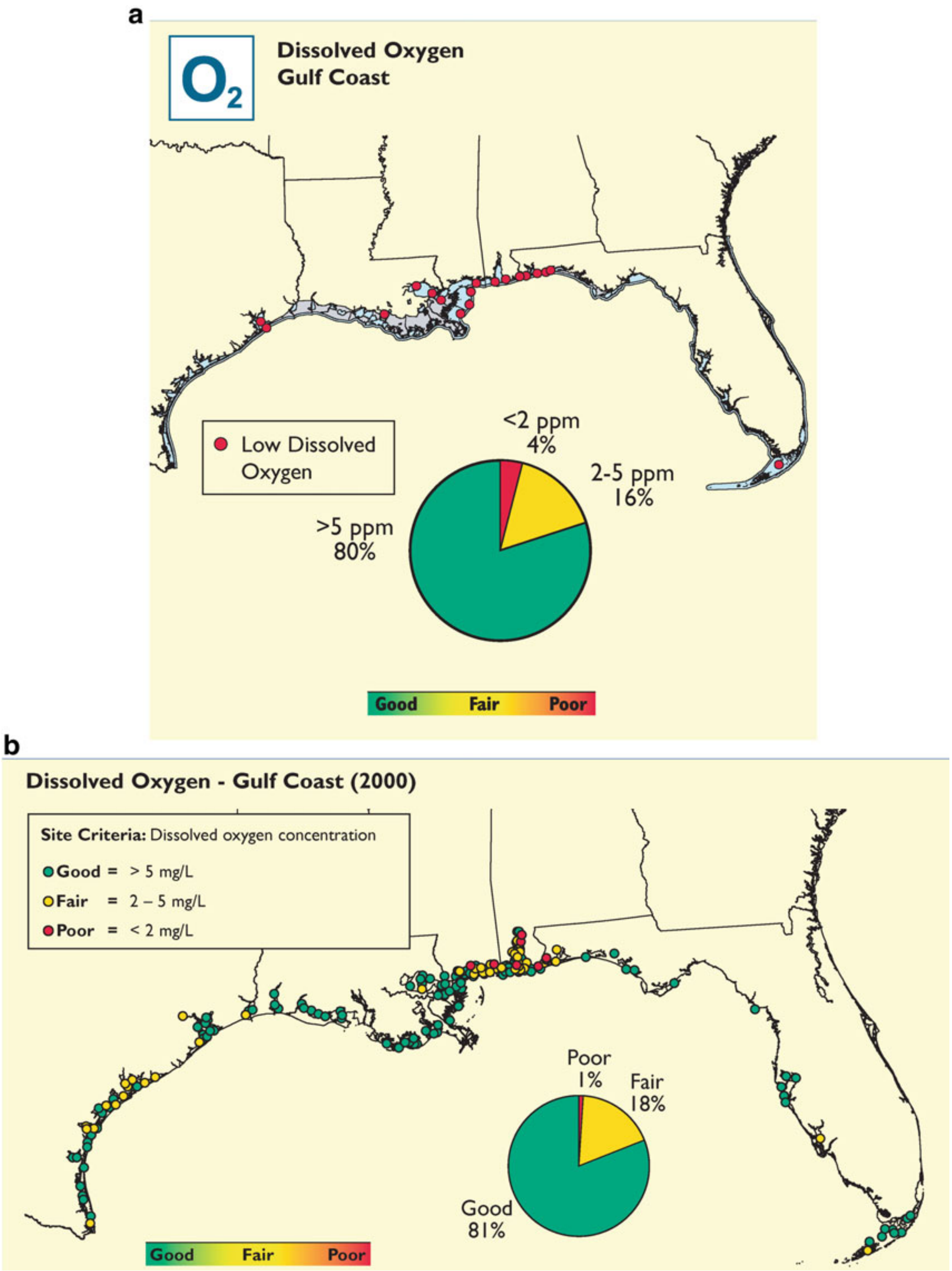

Figure 2.13. Dissolved oxygen concentrations for Gulf of Mexico estuaries: (a) sites with less than 2 ppm in the 2001 assessment (modified from USEPA 2001) and (b) dissolved oxygen criteria from 1996 to 2000 (modified from USEPA 2004).

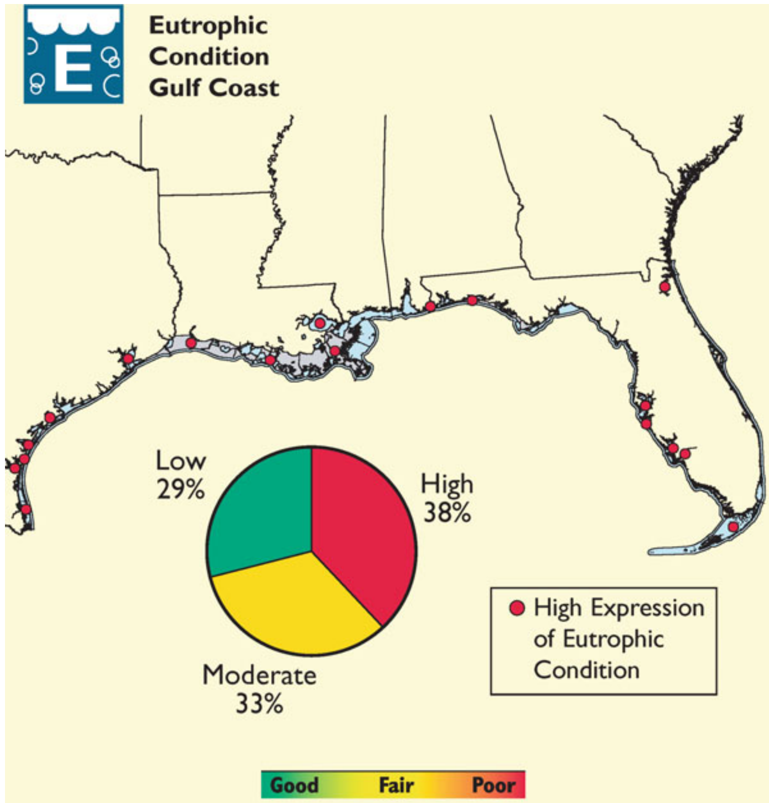

Figure 2.14. Eutrophication condition for estuaries with high expressions of eutrophication (modified from USEPA 2001).

which experiences periodic hypoxia in the summer. Hypoxia in Gulf of Mexico estuaries results from stratification and eutrophication or a combination of the two processes.

The condition of Gulf of Mexico estuaries, as measured by eutrophic condition, was considered poor in the 2001 assessment (USEPA 2001). Expressions of eutrophic condition were high in 38 % of the area in Gulf of Mexico estuaries (Figure 2.14). The symptoms associated with eutrophication were predicted to increase in more than half of the estuaries by 2020 (NOAA 1997). High expressions of chlorophyll *a* occurred in about 30 % of the estuarine area of the Gulf of Mexico. Areas with high chlorophyll *a* were located in Louisiana, Laguna Madre, Tampa Bay, and Charlotte Harbor (Figure 2.15). Florida Bay had a high eutrophic condition but low chlorophyll *a* concentrations. Concentrations of approximately 50 micrograms per liter (μg/L) classified an estuary as having high concentrations of chlorophyll *a*. Chlorophyll *a* concentrations in Florida Bay were as low as 20 μg/L but the bay was considered eutrophic based on other physical, chemical, and ecological characteristics.

A comparison of water quality assessments for the Gulf of Mexico coastal waters over a number of years is summarized in Table 2.5. In the 2004 assessment, DIN concentrations in surface waters of Gulf of Mexico estuaries were rated as good, but DIP concentrations were rated as fair (Figure 2.16a, b (USEPA 2004). High concentrations of DIN (greater than 0.5 mg/L) occurred in 2 % of the estuarine area (Figure 2.16a). Florida Bay sites were rated poor if DIN exceeded 0.1 mg/L or if DIP exceeded 0.01 mg/L based on lower expected nutrient concentrations in tropical and subtropical waters. The Houston Ship Channel, Texas and the Back Bay of Biloxi, Mississippi, exhibited high concentrations of nitrogen and phosphorus. The

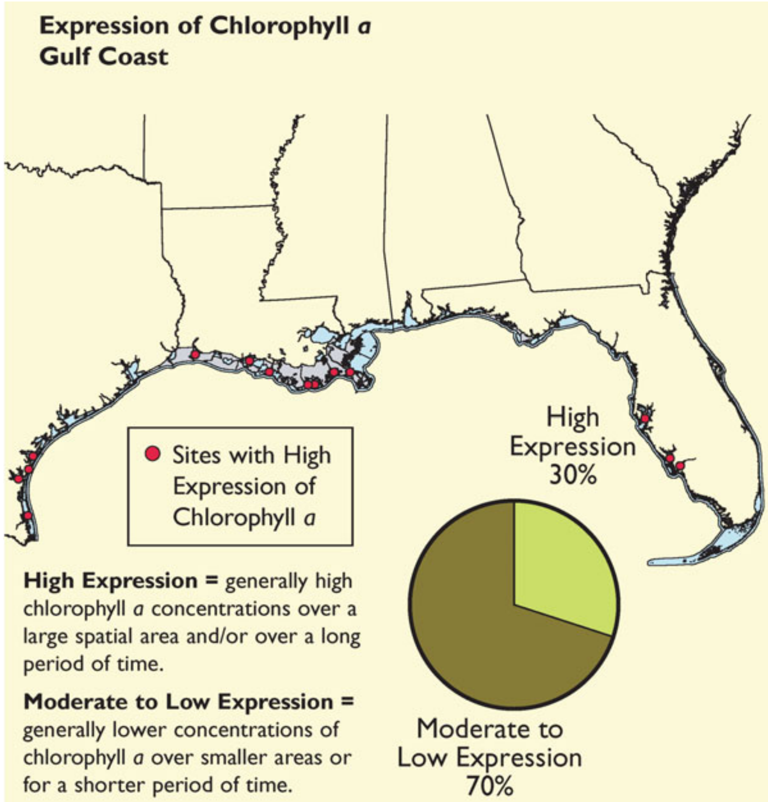

Figure 2.15. Chlorophyll *a* concentrations in Gulf of Mexico estuaries and those locations with high expression of chlorophyll *a* (modified from USEPA 2001).

Perdido River in Alabama was hypoxic and exhibited high chlorophyll *a* concentrations. DIN concentrations above 0.5 mg/L were observed in the Houston Ship Channel, Texas; Calcasieu River, Louisiana; and Back Bay of Biloxi, Mississippi. In Gulf of Mexico coastal waters elevated DIN concentrations were not expected during the summer because freshwater input is usually lower and dissolved nutrients are rapidly taken up by phytoplankton. Elevated DIP concentrations (greater than 0.05 mg/L) occurred in 11 % of Gulf of Mexico estuaries (Figure 2.16b). Tampa Bay and Charlotte Harbor, Florida, had high DIP concentrations because of the natural occurrence of phosphate rocks and anthropogenic sources in their watersheds. Coastal chlorophyll *a* concentrations in Gulf of Mexico estuaries were rated good. Eight percent of the estuarine area in the Gulf Coast region had high concentrations of chlorophyll *a* (Figure 2.16c).

2.3.3 USEPA National Estuarine Condition (2006)

In 2006, a report was issued presenting monitoring data that provided a perspective on the condition of U.S. NEP estuaries (USEPA 2006). The data were collected by the National Coastal Assessment (NCA) group and individual NEPs and their local partners.

The overall condition of NEP estuaries in the Gulf of Mexico for 1997–2003 was rated as fair based on four indices of estuarine condition (Figures 2.17 and 2.18). The assessment was based on data collected from 221 sites sampled in Gulf of Mexico estuaries during the summers of 2000, 2001, and 2002. The region's water quality index was rated as fair

Table 2.5. Summary of Water Quality Assessments for Gulf of Mexico Coastal Waters (modified from NOAA 1997; USEPA 2001, 2004)

Water quality indicator	NOAA 1997	USEPA	
		2001	2004
Eutrophication condition	Poor 38 % high expression of eutrophication	Poor	NA[a]
		High 38 %	
		Moderate 33 %	
		Low 29 %	
Water quality index	NA	NA	Overall fair
			Good 40 %
			Fair 51 %
			Poor 9 %
Chlorophyll *a* concentrations	NA	High 30 %	Overall fair
		Moderate to low 70 %	Good 51 %
			Fair 38 %
			Poor 8 %
DIN concentrations	NA	–	Overall good
			Good 89 %
			Fair 9 %
			Poor 2 %
DIP concentrations	NA	–	Overall fair
			Good 58 %
			Fair 31 %
			Poor 11 %
Water clarity	NA	Overall fair	Overall Fair
		Good 78 % (>1 m)	Good 50 %
		–	Fair 18 %
		Poor 22 % (<1 m)	Poor 29 %
Dissolved oxygen	NA	Overall good	Overall good
		Good 80 %	Good 81 %
		Fair 16 %	Fair 18 %
		Poor 4 % hypoxic	Poor 1 %

[a]*NA* not applicable

(Figures 2.18 and 2.20). A summary of the percentage of estuarine area rated good, fair, poor, or missing for each water quality parameter is presented in Figure 2.19.

Estuarine water quality was rated as 21 % good, 65 % fair, and 13 % poor. The Gulf of Mexico region was rated overall as good for DIN concentrations with 88 % good, 8 % fair and 3 % poor. Elevated DIN concentrations were not expected to occur during the summer in Gulf of Mexico waters because freshwater input is lower and nutrients are rapidly taken up by phytoplankton (Figure 2.20). The estuaries studied were rated fair for DIP concentrations with 22 % rated poor. Gulf Coast estuaries were rated fair overall for chlorophyll *a* concentrations.

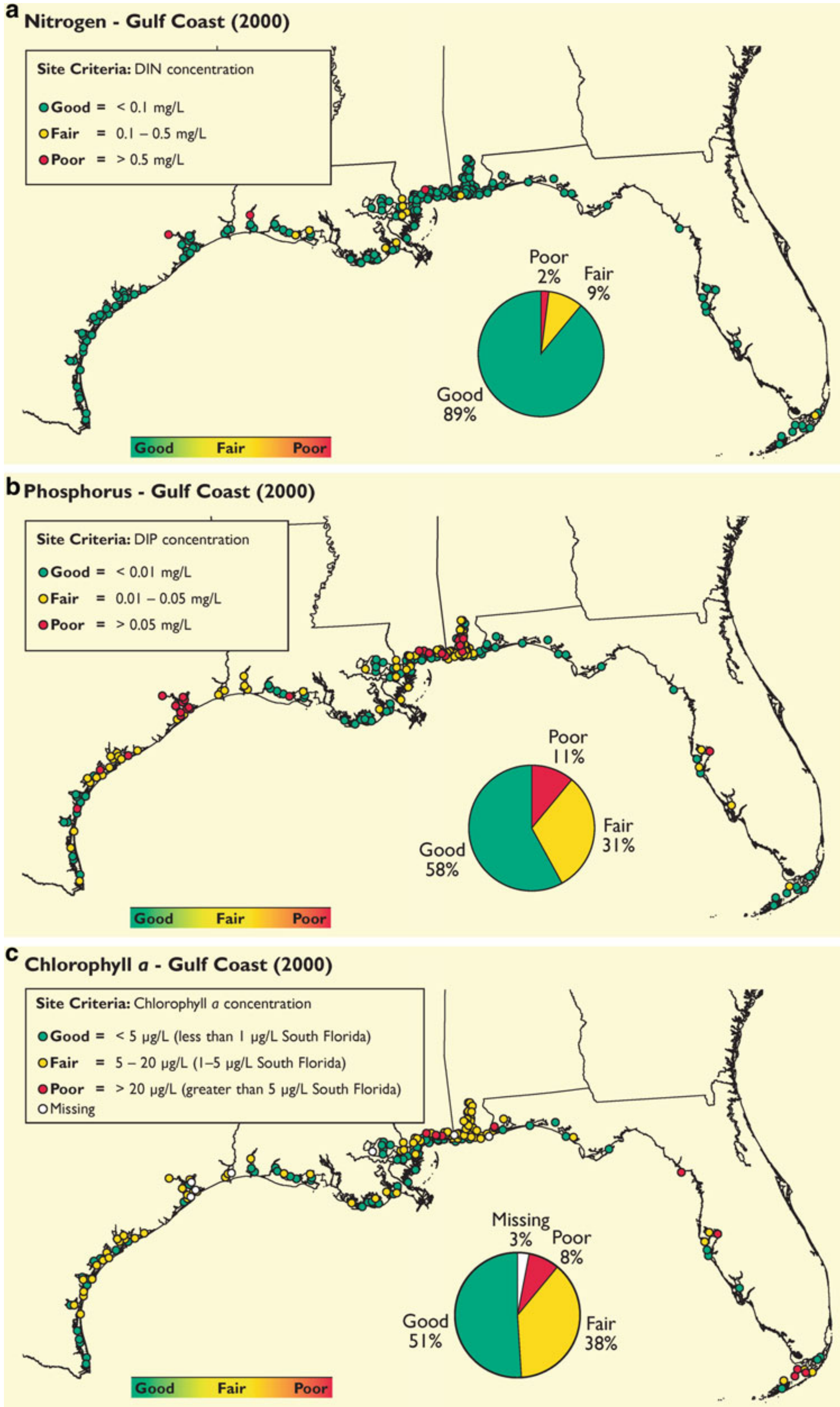

Figure 2.16. (a) Dissolved inorganic nitrogen (DIN) concentrations, (b) dissolved inorganic phosphorus (DIP) concentrations, and (c) chlorophyll *a* concentrations for Gulf of Mexico estuaries in 2000 (modified from USEPA 2004).

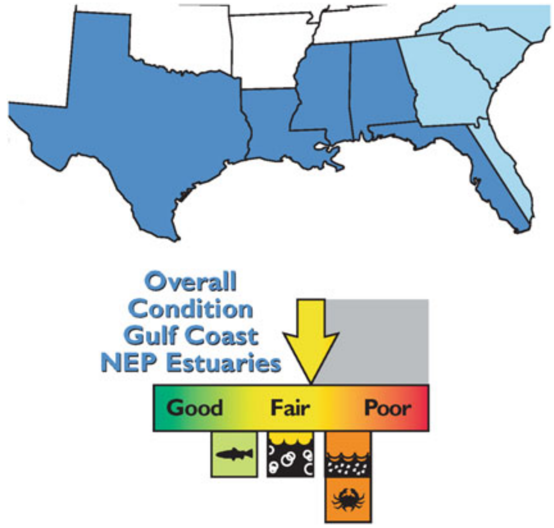

Figure 2.17. Overall rating for National Estuary Program (NEP) sites in the Gulf of Mexico (modified from USEPA 2006).

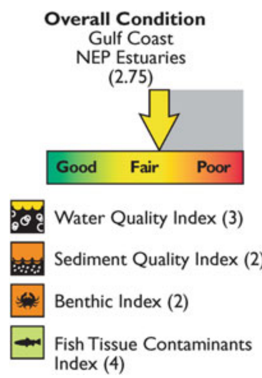

Figure 2.18. Overall condition of representative Gulf of Mexico estuaries for 2000–2003 was judged to be fair (modified from USEPA 2006).

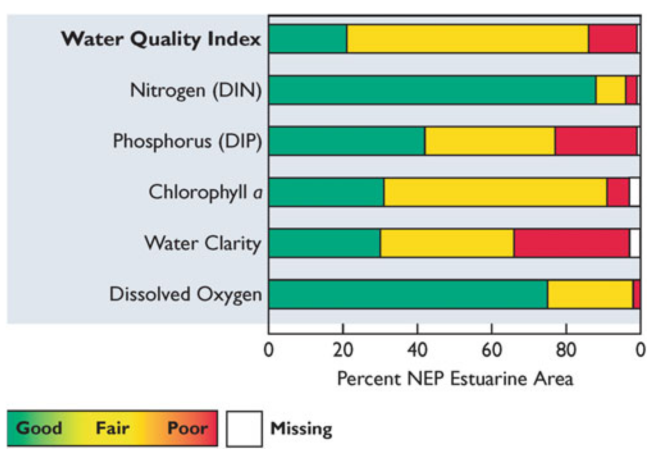

Figure 2.19. Percentage of representative Gulf of Mexico estuaries achieving each rating for individual components of the water quality index for 2000–2003 (modified from USEPA 2006).

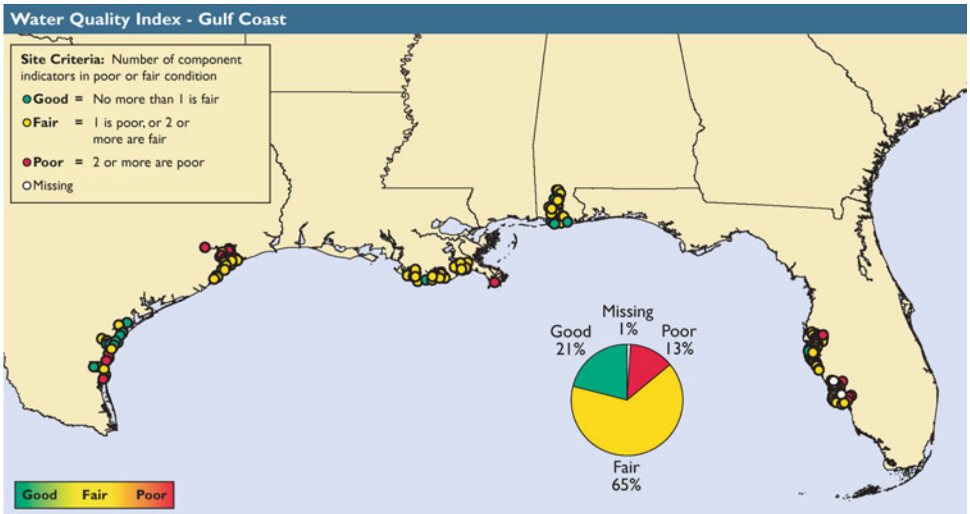

Figure 2.20. Water quality index for representative Gulf of Mexico estuaries for 2000–2003 (modified from USEPA 2006).

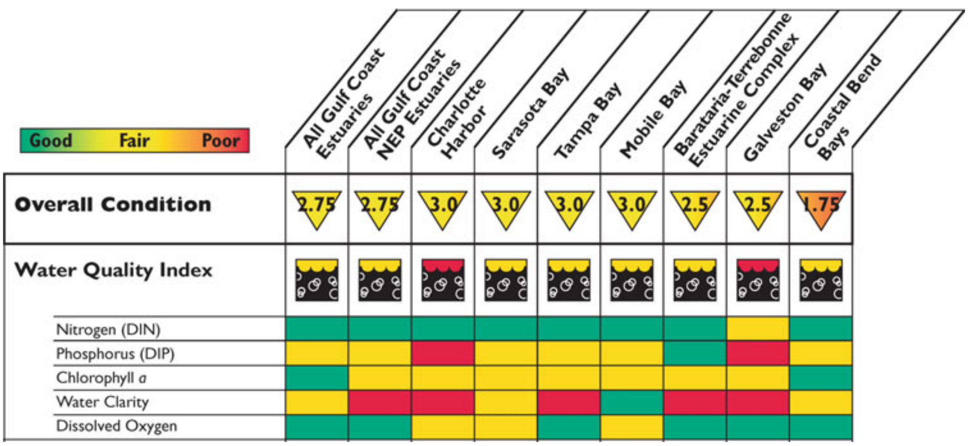

Figure 2.21. Comparison of overall condition and water quality index for Gulf of Mexico estuaries for 2000–2003 (modified from USEPA 2006).

Chlorophyll *a* conditions were rated as 6 % poor, 60 % fair, and 31 % good. Overall water clarity in Gulf of Mexico estuaries was rated as poor with 31 % poor, 36 % fair, and 30 % good. Gulf of Mexico estuaries were rated as good overall for dissolved oxygen concentrations with 2 % poor, 23 % fair, and 75 % good. Survey results of Gulf of Mexico estuaries allowed for a comparison of sites across the region. All Gulf Coast estuaries were rated as fair for overall condition from 2000 to 2003 (Figure 2.21).

2.3.4 USEPA's National Coastal Condition Report III (2008)

In 2008, the third National Coastal Condition Report was issued based on data collected between 2001 and 2002 (USEPA 2008). The overall condition of the coastal waters of the Gulf of Mexico region was rated as fair to poor and water quality was rated as fair (Figures 2.22 and 2.24). The assessment was based on data collected from 487 locations in Florida, Alabama,

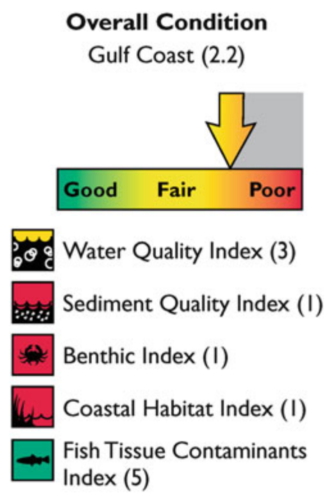

Figure 2.22. Overall condition of Gulf of Mexico coastal waters for 2001–2002 was rated fair to poor (modified from USEPA 2008).

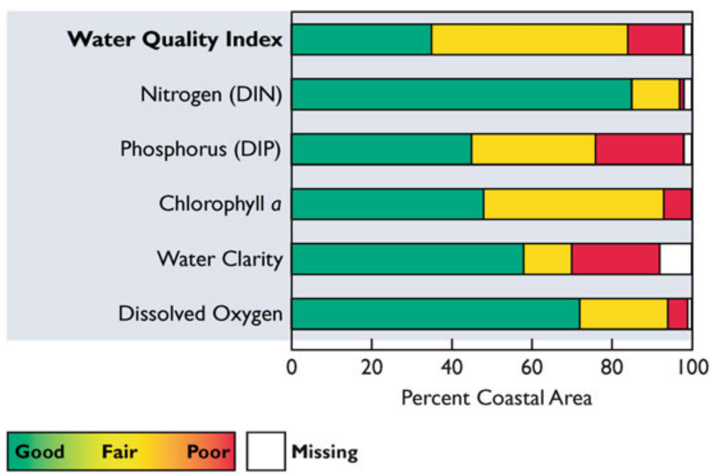

Figure 2.23. Percentage of coastal area achieving each ranking for the water quality index and components of the indicator in the Gulf of Mexico for 2001–2002 (modified from USEPA 2008).

Mississippi, Louisiana, and Texas. Water quality condition was rated as 14 % poor and 49 % fair (Figure 2.23). The water quality index was based on five indicators DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen (Figure 2.24).

Estuaries with poor water quality conditions were found in all five Gulf States but the reason differed among states. At locations in Texas, Louisiana, and Mississippi, poor water clarity and high DIP concentrations contributed to poor water quality ratings. Poor conditions at locations in several Texas bays were due to high chlorophyll *a* concentrations. Only three locations in Louisiana had high concentrations of both DIN and DIP. Many locations rated poor or fair for individual components of the indicator, but were rated fair by the overall water quality index. For comparison, NOAA's Estuarine Eutrophication Survey rated the Gulf Coast as poor for eutrophic condition with 38 % of the coastal area exhibiting high expressions of eutrophication (Bricker et al. 1999).

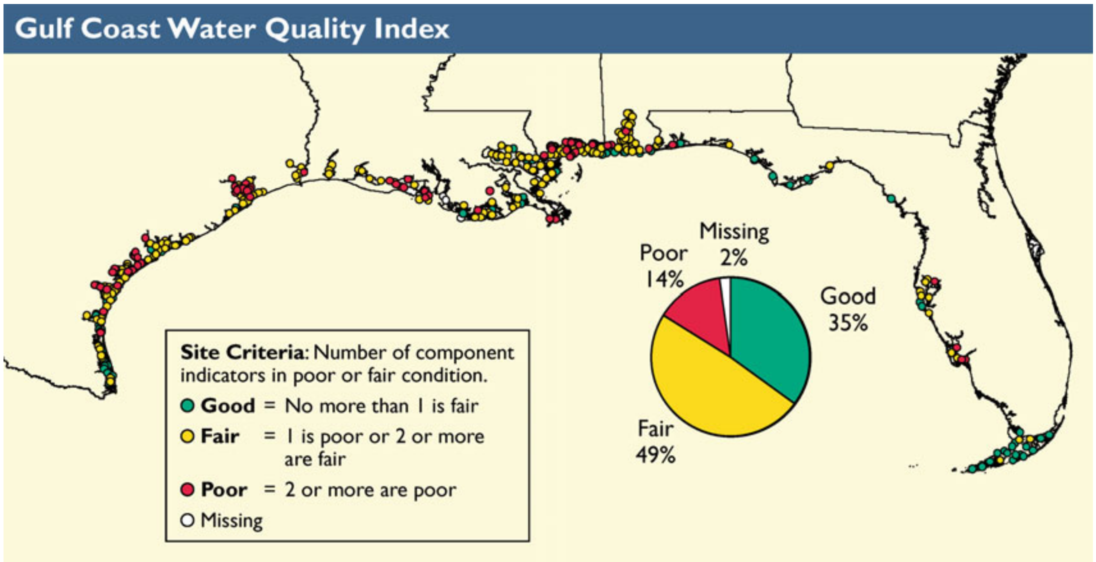

Figure 2.24. Water quality index for Gulf of Mexico coastal waters for 2001–2002 (modified from USEPA 2008).

The northern Gulf of Mexico region was rated as good for DIN concentrations but fair for DIP concentrations from 2001 to 2002. Different criteria for DIN and DIP concentrations were applied in Florida Bay because coastal Florida was considered a tropical estuary. DIN concentrations were rated poor in 1 % of Gulf of Mexico coastal areas including three sites in Louisiana's East Bay, Atchafalaya Bay, and the Intracoastal Waterway between Houma and New Orleans, Louisiana. DIP concentrations were rated poor in 22 % of Gulf of Mexico coastal areas with locations in Tampa Bay and Charlotte Harbor, Florida, highest in DIP due to the occurrence of natural geological formations of exposed phosphate rock in the watersheds and anthropogenic DIP. Gulf of Mexico estuaries were rated fair overall for chlorophyll *a* concentrations from 2001 to 2002 with 7 % poor and 45 % fair. High concentrations of chlorophyll *a* occurred in the coastal areas of all five Gulf States. Water clarity in the northern Gulf of Mexico region was rated fair from 2001 to 2002 with 22 % rated as poor. Lower-than-expected water clarity was observed throughout the northern Gulf of Mexico with poor conditions concentrated in Mississippi, the Coastal Bend region of Texas, and Louisiana. The criteria used to assign water clarity ratings varied across Gulf of Mexico coastal waters based on natural variations in turbidity levels, regional expectations for light penetration related to submerged aquatic vegetation distributions, and local water body management goals. Gulf of Mexico estuaries were rated as fair overall for dissolved oxygen concentrations with 5 % rated as poor. Hypoxia in Gulf of Mexico coastal waters generally resulted from stratification, eutrophication, or a combination of these two conditions. Mobile Bay, Alabama, has regularly experienced hypoxic events during the summer since colonial times, most likely due to natural events (May 1973).

2.3.5 USEPA's National Coastal Condition Report IV (2012)

In 2012, the fourth National Coastal Condition Report was issued based on data collected between 2003 and 2006 (USEPA 2012). The overall condition and water quality of the coastal waters of the Gulf of Mexico region were rated as fair (Figures 2.25 and 2.27). The assessment was based on data collected from 879 locations in Florida, Alabama, Mississippi, Louisiana, and

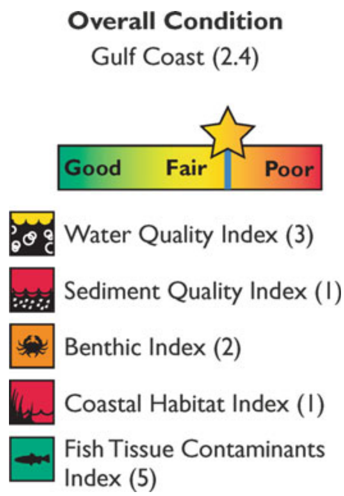

Figure 2.25. Overall condition of Gulf of Mexico coastal waters for 2003–2006 was rated fair (modified from USEPA 2012).

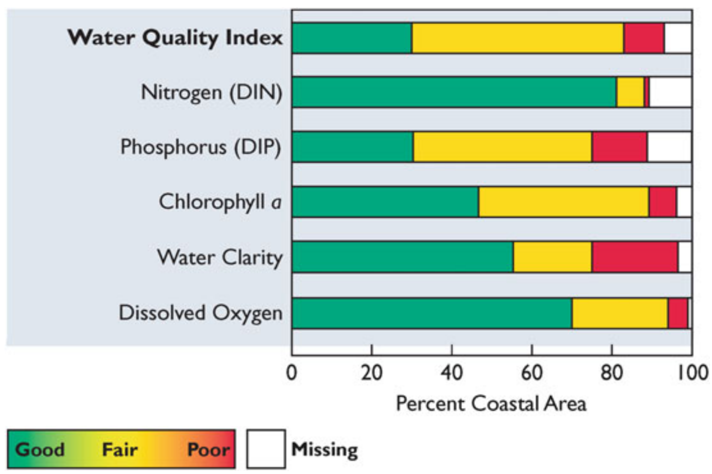

Figure 2.26. Percentage of coastal area achieving each ranking for the water quality index and components of the indicator in the Gulf of Mexico for 2003–2006 (modified from USEPA 2012).

Texas. Water quality condition was rated as 10 % poor and 53 % fair (Figure 2.26). Due to hurricanes Katrina and Rita, Alabama and Louisiana did not collect data in 2005. As before, the water quality index was based on DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Poor water quality conditions were found across the region but the reason differed among states. Poor water clarity, high DIP concentrations, and high chlorophyll *a* concentrations contributed to poor water quality ratings. Three sites in Louisiana had high concentrations of DIN and DIP. A lower percentage of Gulf of Mexico coastal areas rated good for the water quality index than the component indicators as indications of poor or fair conditions did not always coincide. The NOAA Estuarine Eutrophication Survey in 1999 rated the Gulf Coast poor for eutrophic condition with approximately 38 % of the coastal area exhibiting high expressions of eutrophication (Bricker et al. 1999). The northern Gulf of Mexico was rated good for DIN concentrations and fair for DIP concentrations. Criteria for DIN and DIP concentrations in Florida Bay differed from other areas because it is considered to be a tropical estuary. DIN

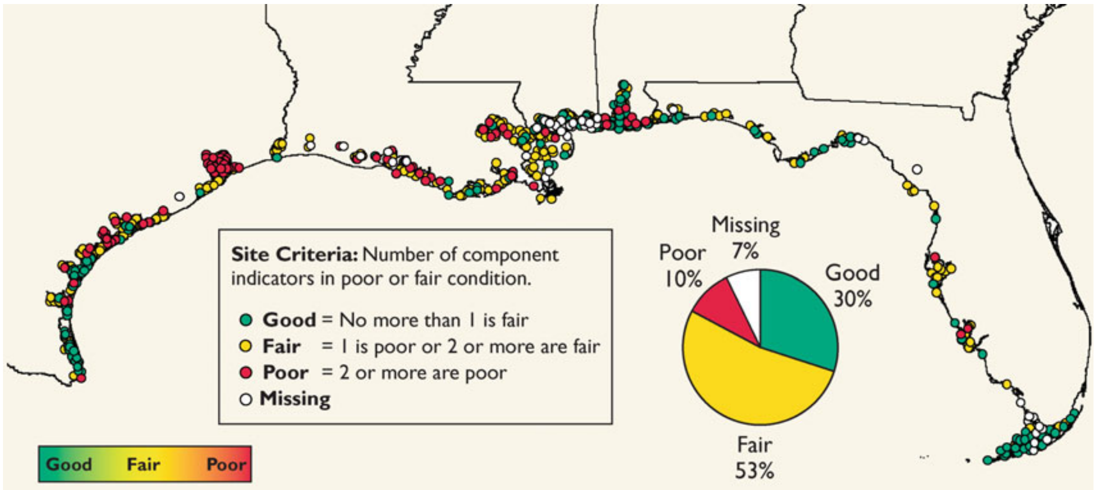

Figure 2.27. Water quality index for Gulf of Mexico coastal waters for 2003–2006 (modified from USEPA 2012).

concentrations were poor in 1 % of the coastal area at several sites in Louisiana and Texas from 2003 to 2004. DIP concentrations were rated poor for 14 % of the coastal area including sites in Tampa Bay and Charlotte Harbor, Florida, due to naturally occurring phosphate rock in the watersheds and anthropogenic sources of DIP. The region was rated fair for chlorophyll *a* concentrations with high concentrations of chlorophyll *a* occurring in all five Gulf Coast States. Water clarity in the Gulf of Mexico region was rated fair with 21 % of the coastal area rated poor. Poor water clarity conditions were observed most frequently in Texas and Louisiana. The region was rated good for dissolved oxygen concentrations with less than 5 % (4.8 %) of the coastal area rated poor. Hypoxia generally resulted from stratification, eutrophication, or a combination of these two conditions. Mobile Bay, Alabama, experiences regular hypoxic events during the summer. These occurrences have been known since colonial times and are believed to be natural events (May 1973) (Figure 2.27).

2.3.6 State of the Bays

In the previous sections, water quality was summarized on a regional basis for the northern Gulf of Mexico highlighting sites with specific water quality issues. In this summary, individual bays and estuarine complexes in the Gulf of Mexico are considered to provide a finer spatial scale view of water quality in Gulf of Mexico estuaries. These summaries draw on information produced as part of the NEP. The NEP was established under Section 320 of the 1987 Clean Water Act Amendments as a USEPA effort to protect and restore the water quality and ecological integrity of major U.S. estuaries. At the time of assessment, there were 28 estuaries designated of national significance, and six of them were located in the northern Gulf of Mexico.

2.3.6.1 Texas Bays

Water quality for bays in the state of Texas is summarized based on monitoring data collected in Galveston Bay and the Coastal Bend Bays and Estuaries (CBBE) complex (Figure 2.28). Both bays host an NEP.

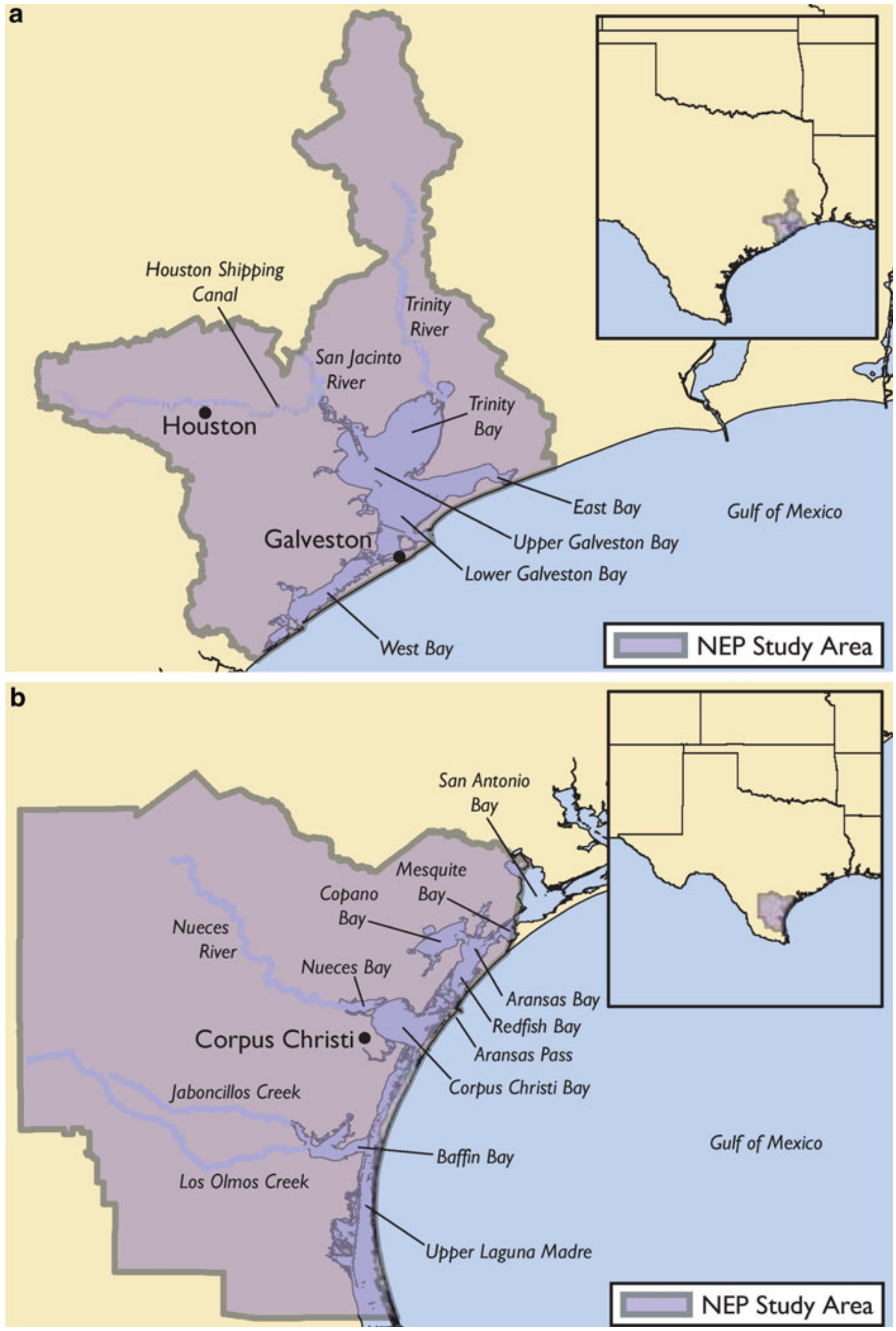

Figure 2.28. Map of National Estuary Program Study Areas (a) Galveston Bay Estuary Complex and (b) Coastal Bend Bays and Estuaries, Texas (modified from USEPA 2006).

Galveston Bay is a subtropical estuary located on the southeastern shore of the upper Texas Gulf Coast. The bay is composed of five major sub-bays: Trinity, Upper Galveston, Lower Galveston, East, and West bays. The combined area of the five sub-bays was estimated to be 1,554 km^2 (600 mi^2) surrounded by 1,885 km (1,171 mi) of shoreline (GBEP 2005). The estuary receives inflow from the Trinity and San Jacinto rivers and is bordered by low-lying wetlands, two barrier islands, and a peninsula. The waters of Galveston Bay were considered well mixed and shallow averaging 2.1 m (7 ft) and shallower in places due to oyster reefs (GBEP 2005). The bay volume has increased over the last 50 years due to natural and anthropogenic subsidence, sea level rise and dredging (Lester and Gonzalez 2003). Major habitats in the bay include estuarine and freshwater marsh, mudflats, sea grass beds, oyster reefs, and open water. The watershed includes a variety of habitats ranging from open prairies and coastal wetlands to riparian hardwoods and pine-dominant forests. These habitats support numerous plant, fish, and wildlife species. Galveston Bay is extensively used for recreational and commercial activities. Potential human impacts are large due to the surrounding populations. Galveston Bay is one of the largest sources of seafood for Texas and a major national oyster-producing estuary. The oysters, crabs, shrimp, and finfish harvested from Galveston Bay were estimated to be worth approximately $19 million per year (Lester and Gonzalez 2003). At the time, one-third of the Texas commercial fishing income and more than one-half of the state's recreational fishing expenditures came from Galveston Bay (GBEP 2005). The Port of Houston was the second largest port in the United States in tonnage and the eighth largest port in the world in 2002 (Lester and Gonzalez 2003). Along with the port cities of Texas City and Galveston, the Port of Houston supports petrochemical industries that were the largest in the nation and the second largest in the world in 2006 (Port of Houston Authority 2006). These industries produced one-half of the nation's chemicals and represented one-third of the nation's petroleum refining capacity. Extending back from the river mouths, the Galveston Bay watershed covered 85,469 km^2 (33,000 mi^2) at the time including the metropolitan areas of Houston-Galveston and Dallas-Fort Worth, home to nearly half of the population of Texas in 2005 (GBEP 2005). Galveston Bay environmental concerns include wetland loss and habitat degradation, point and non-point source pollution, and chemical and refined product spills from barges and industry (Lester and Gonzalez 2003). Non-point source pollution in Galveston Bay includes runoff from thousands of gas stations, residential lawns, failing septic systems, driveways, parking lots, industries, farms, and other sources. Accidental spills and the deliberate dumping of oil and other contaminants harm the habitat and living resources of Galveston Bay. Galveston Bay was also subject to introductions of aquatic and terrestrial exotic nuisance species, contaminated runoff from urbanized areas, and the diversion of fresh water inflows. Some sediment in the Houston Ship Channel exceeded levels of concern for a number of hazardous chemicals including PCBs, DDT (dichlorodiphenyltrichloroethane), dioxin, and metals in 2006.

The Coastal Bend Bays and Estuaries (CBBE) complex include three of the seven estuaries along the Texas coast. The northerly portion of the CBBE Program (CBBEP) includes San Antonio, Mesquite, Redfish, Copano, and Aransas Bays. The middle portion includes Nueces Bay and Corpus Christi Bay, the largest of the bays, and discharges into the Gulf of Mexico at Aransas Pass. The most southerly portion includes Upper Laguna Madre and Baffin Bay. The area was estimated to include 121 km (75 mi) of Texas coastline and 1,334 km^2 (515 mi^2) of water (CBBEP 2005). The area included barrier islands, tidal marshes, sea grass meadows, open bays, oyster, and serpulid worm reefs, wind tidal flats, and freshwater marshes. The CBBEP supports recreational, commercial, industrial, and residential uses including sport boat fishing, bird watching, and windsurfing. The commercial fishing industry annually harvested, on average, more than eight million pounds of finfish, shrimp, and crab (Tunnell et al. 1996). The area was estimated to contain 40 % of the state's total sea grass acreage, nursery areas for fish and shellfish, and habitats for other wildlife including birds, sea mammals, and marine turtles (CBBEP 1998). Corpus Christi Bay was the nation's fifth largest port and included the third largest refinery and petrochemical complex in the United States in 2005 (CBBEP 2005). The region's population was 550,000 in 1995 and was projected to be nearly one million by 2050

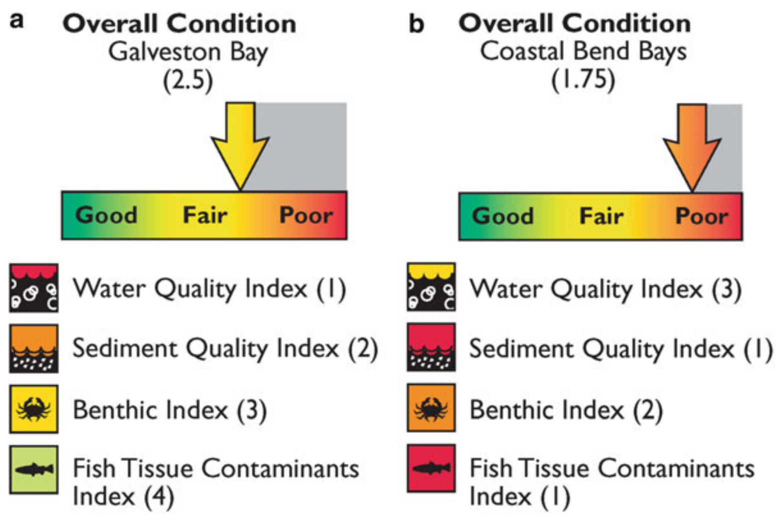

Figure 2.29. Overall condition of (a) Galveston Bay and (b) Coastal Bend Bays in 2000 (modified from USEPA 2006).

(CBBEP 1998). Freshwater was in short supply in semiarid southern Texas due to many competing demands. Residential and business water use in this region was expected to increase by 50 % by 2050 and industrial demand was expected to double (CBBEP 1998). Freshwater is vital to the human population and is closely tied to the health of coastal ecosystems.

In the 2006 assessment, the overall condition of Galveston Bay and the Coastal Bend was rated as fair to poor, respectively (Figure 2.29). The water quality index was rated poor for Galveston Bay and fair for the Coastal Bend (Figures 2.29 and 2.31). In NOAA's Estuarine Eutrophication Survey in 1997, Galveston Bay was listed as having medium chlorophyll *a* concentrations and medium-to-low DIN and DIP concentrations with elevated concentrations occurring in tidal freshwater areas (NOAA 1997). In 2006, Galveston Bay was rated fair for DIN concentrations and poor for DIP concentrations. Thirteen percent of the estuarine area was rated poor for DIN concentrations, and 68 % of the estuarine area was rated poor for DIP concentrations (Figure 2.30). Galveston Bay was rated fair overall for chlorophyll *a* concentrations with 4 % poor, 71 % fair, and 13 % good with data unavailable for 12 % of the estuarine area. Water clarity in Galveston Bay was rated poor overall because 28 % of the estuarine area was rated poor. Water clarity for turbid estuaries was rated poor if light penetration at 1 m (3.3 ft) was less than 10 % of surface illumination. Dissolved oxygen conditions in Galveston Bay were rated as good overall with 71 % good and 29 % fair (Figure 2.31).

In NOAA's Estuarine Eutrophication Survey in 1997, the Coastal Bend was listed as having medium to hyper-eutrophic chlorophyll *a* levels and low to high DIN and DIP concentrations with elevated concentrations occurring in tidal freshwater areas (NOAA 1997). In 2006, the Coastal Bend was rated good overall for DIN concentrations with 99 % of the estuarine area rated as good (Figure 2.30) and was rated fair overall for DIP concentrations with 4 % as poor, 46 % fair, and 50 % good (Figure 2.30). Chlorophyll *a* concentrations in the Coastal Bend Bays were rated good overall with 5 % rated as poor, 40 % fair, and 55 % good. Water clarity in the Coastal Bend was rated fair overall because 16 % of the estuarine area was rated poor. In Corpus Christi and Aransas bays, water clarity was rated poor if light penetration at 1 m (3.3 ft) was less than 10 % of surface illumination. Dissolved oxygen concentrations in the Coastal Bend were rated as good overall with 70 % good and 30 % fair.

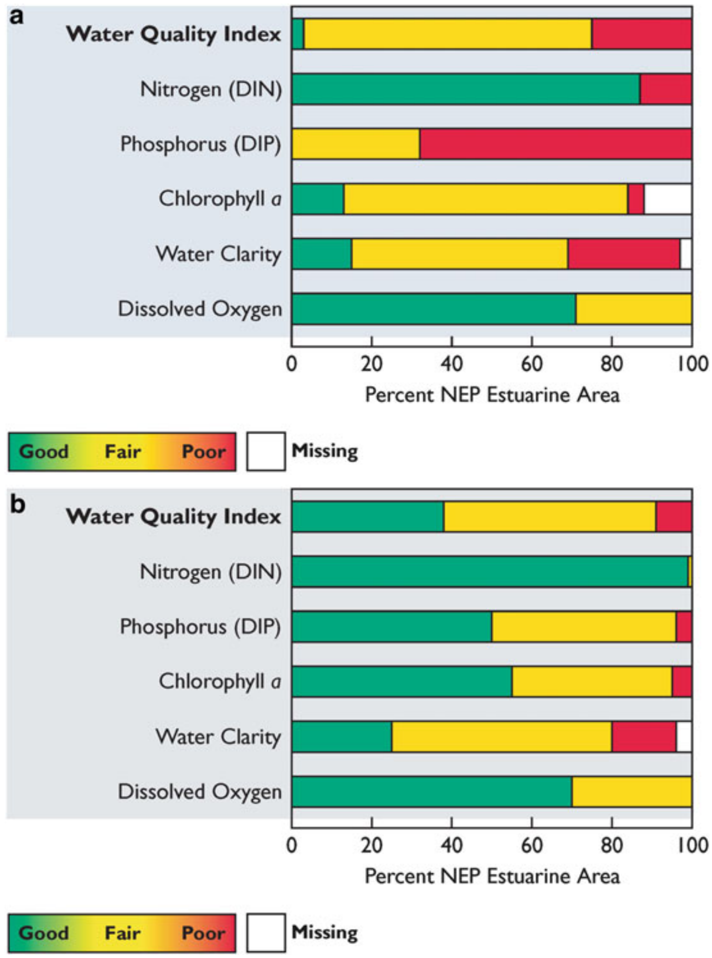

Figure 2.30. Percentage of estuarine area achieving each rating for water quality index and its components (a) Galveston Bay and (b) Coastal Bend Bays (modified from USEPA 2006).

2.3.6.2 Louisiana Bays

Water quality for bays in the state of Louisiana is summarized based on monitoring data collected in the Barataria-Terrebonne Estuary (Figure 2.32). The Barataria-Terrebonne Estuary hosts an NEP. The Barataria-Terrebonne estuary is located between the Mississippi and Atchafalaya rivers in southern Louisiana and covers approximately 16,800 km^2 (6,500 mi^2) (Caffey and Breaux 2000). Bayou Lafourche separates the area into two basins: Barataria Basin to the east and Terrebonne Basin to the west. The mixing of saltwater and freshwater begins offshore where water, sediment, nutrients, and pollutants from the Mississippi River comingle with the salty water of the Gulf of Mexico. Industrial and municipal effluents enter the Mississippi River between Baton Rouge and New Orleans and contribute to nutrient and contaminant loads in the estuary system. Several natural and man-made waterways transect the estuary system including the Gulf Intracoastal Waterway and the Barataria Waterway. Open water and wetlands were the predominant land-use classifications in the region, and it had been increasing in area since 1956. More than three-quarters of the area (approximately 12,900 km^2 or 5,000 mi^2) was classified as open water or wetlands with approximately 4,050 km^2 (1,562 mi^2) used for urban and agricultural activities (Moore and Rivers 1996).

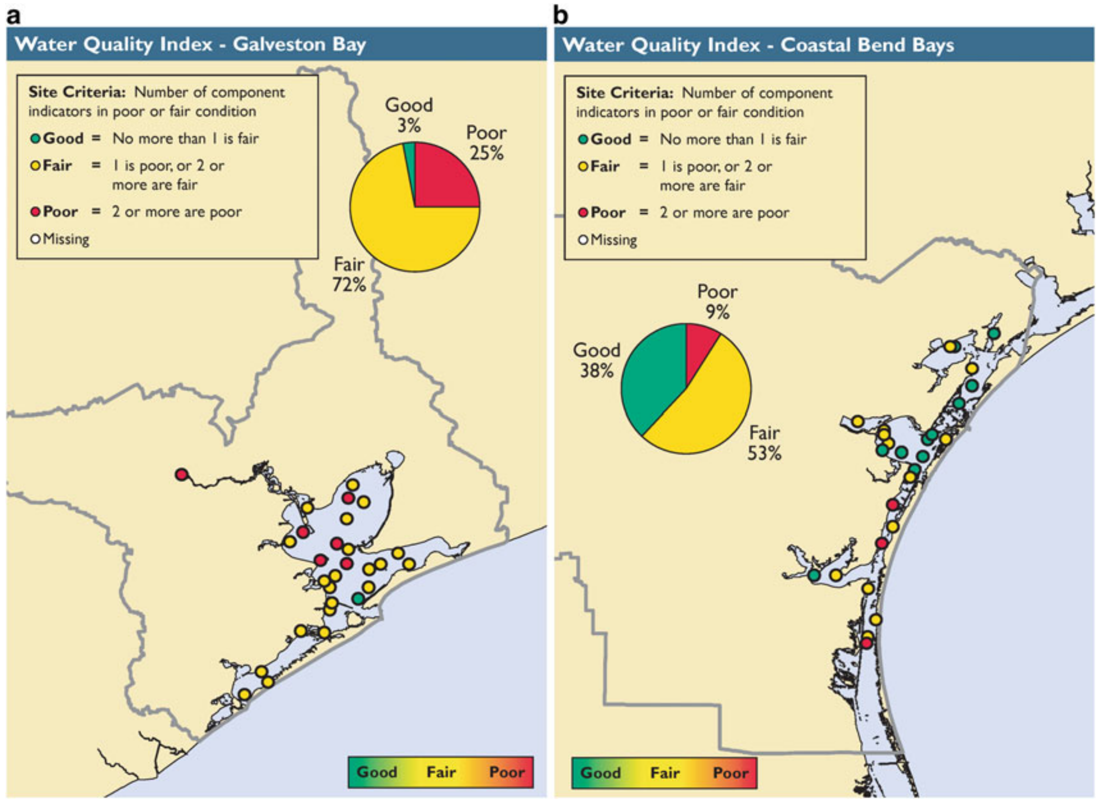

Figure 2.31. Water quality index for (a) Galveston Bay and (b) Coastal Bend Bays in 2000–2001 (modified from USEPA 2006).

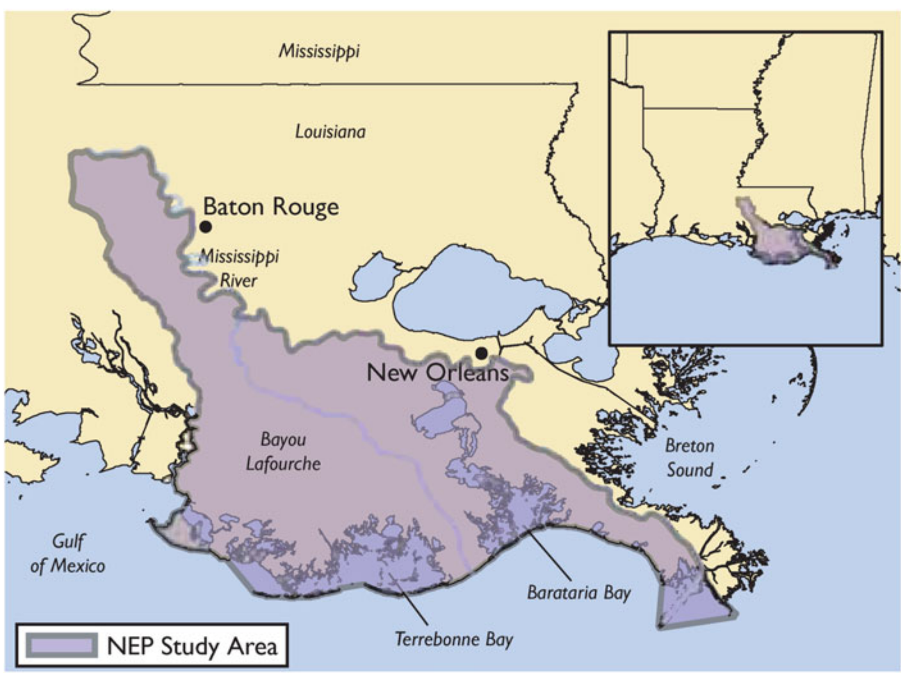

Figure 2.32. Map of Barataria-Terrebonne Estuary, Louisiana (modified from USEPA 2006).

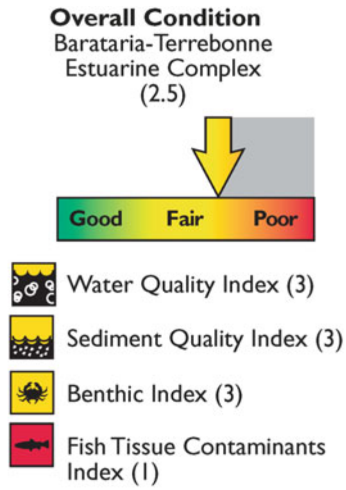

Figure 2.33. Overall condition of Barataria-Terrebonne estuarine area (modified from USEPA 2006).

The issues affecting the area include habitat loss, hydrological modification, reduced sediment flows (reduction in sediment inputs), eutrophication, pathogen contamination from untreated sewage and stormwater discharges, toxic substances, and declines in living resources (Battelle 2003). Sediment loss (depletion) in conjunction with the subsidence (sinking) of marshes was considered the most significant problem in the Barataria-Terrebonne Estuarine Complex at the time. The construction of levees to control flooding diminished freshwater inflow and sediments reaching the estuaries. Sea level rise, erosion, canal dredging, and the construction of navigation and oil-exploration channels contributed to wetland loss. Hydrological modifications had created paths for high salinity waters to intrude inland impacting freshwater plants causing animals to adapt or relocate. At the time, about 38.8 km^2 (15 mi^2) of wetlands were being lost each year and 0.0002 km^2 (0.05 acres) of the coastal wetlands was turning to open water every 15 minutes (min) (BTNEP 2002). The loss of habitat adversely affects the health of fish and wildlife populations and stymies economic development.

The overall condition of the Barataria-Terrebonne Estuarine Complex was rated fair based on four indices of estuarine condition, and water quality was also rated as fair (Figure 2.33). Figure 2.34 summarizes the percentage of estuarine area rated as good, fair, poor, or missing for each parameter considered. This assessment was based on data from 25 locations sampled in 2000 and 2001.

Based on survey results, the water quality index for the Barataria-Terrebonne Estuarine Complex was rated fair (Figure 2.35). In NOAA's Estuarine Eutrophication Survey in 1997, Barataria Bay was listed as having high to hyper-eutrophic chlorophyll *a* concentrations and high DIN and DIP concentrations (NOAA 1997). In the same report, the Terrebonne and Timbalier bays were listed as having high chlorophyll *a* and DIP concentrations and moderate DIN concentrations. In the 2006 report, DIN and DIP concentrations in the estuarine area were rated as good overall. For both component indicators, 4 % were rated poor, 16 % fair, and 80 % good. Chlorophyll *a* concentrations in the Barataria-Terrebonne Estuarine Complex were rated fair overall with 4 % of the estuarine area rated poor, 64 % fair, and 32 % good. Water clarity was rated poor overall with 52 % of the estuarine area rated poor, 20 % fair, and 28 % good. Dissolved oxygen conditions in the estuarine area were rated good overall with none of the estuarine area rated poor, 4 % fair, and 96 % good. Eutrophic conditions and nutrient levels in the Barataria-Terrebonne Estuarine Complex were monitored at a series of 15 locations; all were classified as having medium or high nutrient conditions under NOAA guidelines. During

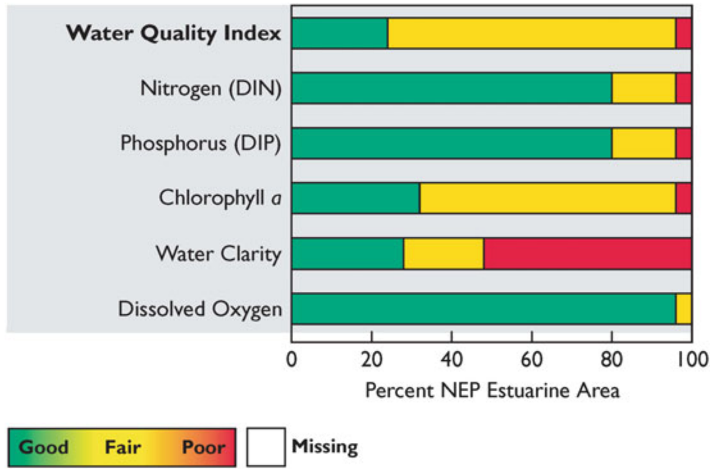

Figure 2.34. Percentage of Barataria-Terrebonne estuarine area achieving each rating for each component indicator of the water quality index (modified from USEPA 2006).

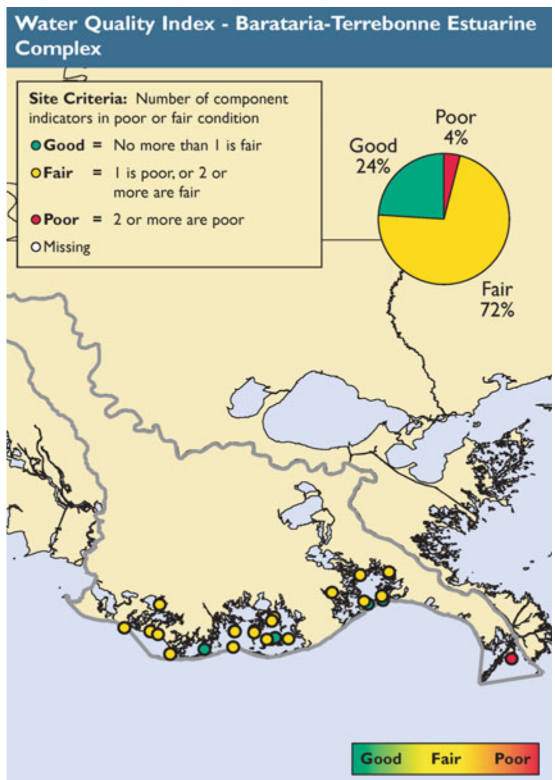

Figure 2.35. Water quality index for Barataria-Terrebonne Estuarine Complex, 2000–2001 (modified from USEPA 2006).

the 20 years before the assessment, measurements of chlorophyll *a* levels provided evidence of eutrophication with many locations exhibiting an increase in chlorophyll *a* concentrations over time (Rabalais et al. 1995). Hypoxic events were being induced by inflows of wastewater treatment plant effluent and agricultural runoff. Nearshore bottom water dissolved oxygen concentrations varied from 4 to 8 mg/L, and indications of persistent hypoxia from mid-May to mid-September were observed (Rabalais et al. 1995). Hypoxic conditions occurred in poorly flushed areas, deeper channels, and areas receiving organic loading from sewage or other wastewater outfalls. Pathogens from sewage pollution were associated with illnesses in humans who swam in contaminated waters or consumed contaminated oysters. Fecal coliform came from poorly functioning septic systems, pastureland runoff, and animal waste. Copper, lead, arsenic, chromium, and cadmium concentrations declined in concentration since the 1980s, whereas mercury levels remained fairly constant. Although contamination was fairly widespread, the areas of most concern were on the periphery such as Oyster Bayou and Tiger Pass. Toxics were detected in fish and crustaceans of the Barataria-Terrebonne Estuarine Complex including pesticides, metals, volatile organic compounds (VOCs), and PCBs (Rabalais et al. 1995).

2.3.6.3 Mississippi and Alabama Bays

Water quality for bays in Mississippi and Alabama is summarized based on monitoring data for Mobile Bay (Figure 2.36). Mobile Bay hosts an NEP. Mobile Bay is a submerged river valley at the transition between the coastal zone of the Mobile Bay watershed and the Gulf of Mexico. The Mobile Bay watershed covered approximately 115,500 km^2 (44,600 mi^2) including two-thirds of Alabama and portions of Mississippi, Georgia, and Tennessee at the time of assessment (NOAA 1985; Mobile Bay NEP 2002). At that time, it was the fourth largest watershed by flow volume in the United States and the sixth largest river system in area (Mobile Bay NEP 2002). The surface waters of Mobile Bay were estimated to cover approximately 1,060 km^2 (409 mi^2) with an average depth of approximately 3 m (10 ft) (NOAA 1985; Mobile Bay NEP 2002). Freshwater flows into the bay through several rivers (e.g., the Mobile-Tensaw, Blakely, Apalachee, Dog, Deer, Fowl, and Fish rivers). The bay's primary opening to the Gulf of Mexico is the Main Pass, located between Dauphin Island and the Fort Morgan Peninsula. Covering approximately 749 km^2 (289 mi^2) of marsh, swamp and forested wetlands, the Mobile-Tensaw River Delta was the largest intact delta in the United States at the time of assessment (Wallace 1994; Auburn University 2004). The bay basin includes barrier islands,

Figure 2.36. Map of Mobile Bay, Alabama (modified from USEPA 2006).

tidal marshes, cypress swamps, bottomland hardwoods, and oyster reefs. Portions of Mobile Bay support commercial fisheries, industry, tourism and recreation, and coastal development. It was estimated that 4.85 million metric tons (5.35 million tons) of sediment annually entered the estuary with 33 % deposited in the Mobile-Tensaw Delta, 52 % in the bay, and 15 % flowing out into the Gulf of Mexico (Mobile Bay NEP 2002). Mobile Bay's salinity regime is complex and highly variable because winds and tides affect the inflow of salty Gulf of Mexico waters into the bay. Salinity varied with depth in the bay and in the major river channels (Braun and Neugarten 2005).

The overall condition of Mobile Bay was rated as fair based on four indices of estuarine condition, and water quality was rated as fair (Figures 2.37 and 2.39). The assessment of the estuarine status rated each parameter in the water quality as good, fair, poor, or missing (Figure 2.38). The water quality index for Mobile Bay was rated as fair based on data collected at 66 locations (Figure 2.39). In NOAA's 1997 Estuarine Eutrophication Survey, Mobile Bay

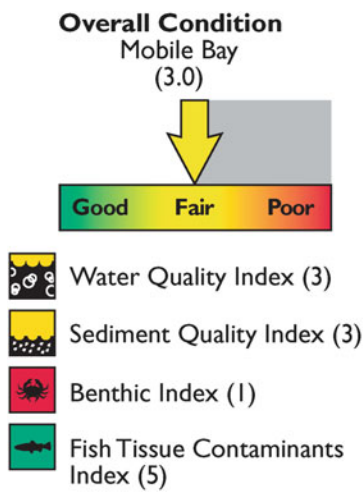

Figure 2.37. Overall condition of Mobile Bay estuarine area (modified from USEPA 2006).

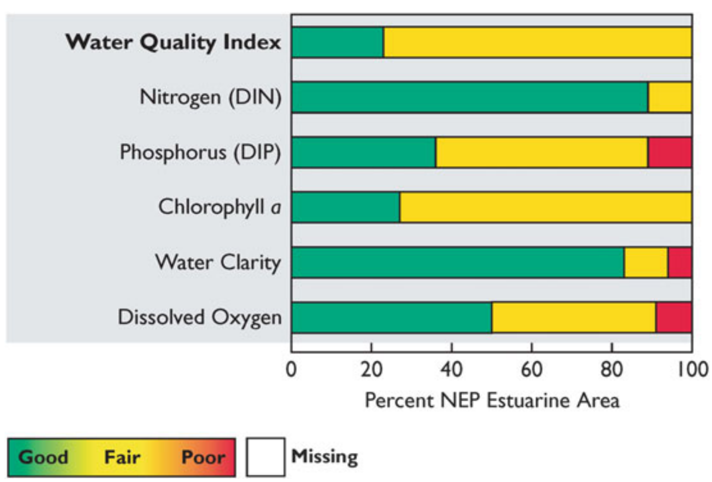

Figure 2.38. Percentage of Mobile Bay estuarine area achieving each indicator of water quality (modified from USEPA 2006).

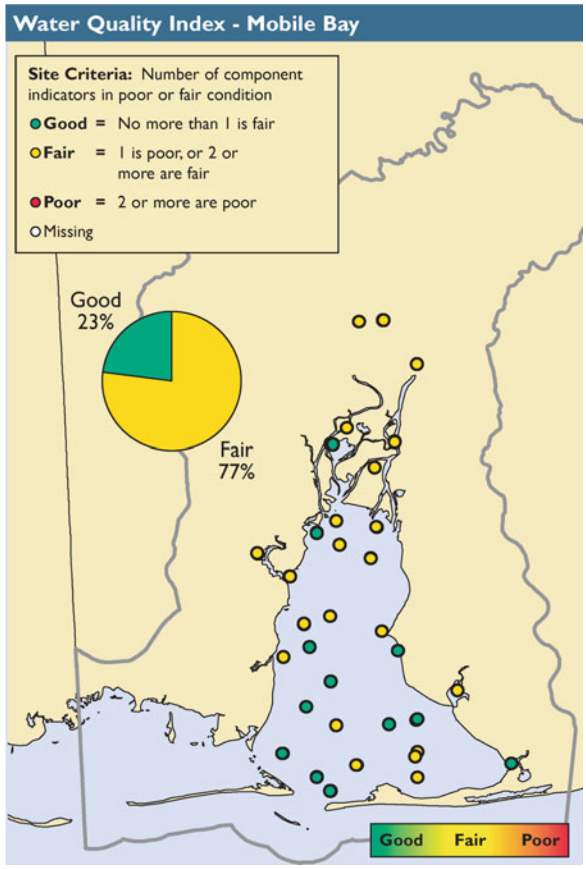

Figure 2.39. Water quality index for Mobile Bay, 2000–2001 (modified from USEPA 2006).

was listed as having medium levels of chlorophyll *a* and medium-to-low DIN and DIP concentrations (NOAA 1997).

DIN and DIP concentrations in Mobile Bay were rated good and fair overall, respectively. Concentrations of DIN were rated as good in 89 % of the estuarine area and fair in the remaining 11 %. Within the estuarine area, 11 % was rated poor for DIP concentrations, 53 % fair, and 36 % good. Chlorophyll *a* concentrations were rated as fair overall. No poor chlorophyll *a* conditions occurred with 73 % rated as fair and the remaining 27 % rated good. Water clarity in Mobile Bay was rated good overall. Mobile Bay experiences high river flow which causes naturally turbid water. Water clarity was rated as poor in 6 % of the estuarine area, 11 % fair, and 83 % good. Dissolved oxygen conditions in Mobile Bay were rated as fair overall with 9 % rated poor, 41 % fair, and 50 % good.

2.3.6.4 Florida Bays

Water quality for bays in the state of Florida is summarized based on monitoring data for Tampa and Sarasota bays (Figure 2.40). Both bays host NEPs.

At the time, Tampa Bay was Florida's largest open water estuary spanning approximately 1,036 km^2 (400 mi^2) and draining approximately 5,957 km^2 (2,300 mi^2) of land (Figure 2.40a) (TBEP 2003). The watershed includes the upper reaches of the Hillsborough River, east to the headwaters of the Alafia River, and south to the headwaters of the Manatee River. Freshwater enters the bay from the Lake Tarpon Canal and the Hillsborough, Palm, Alafia, Little Manatee,

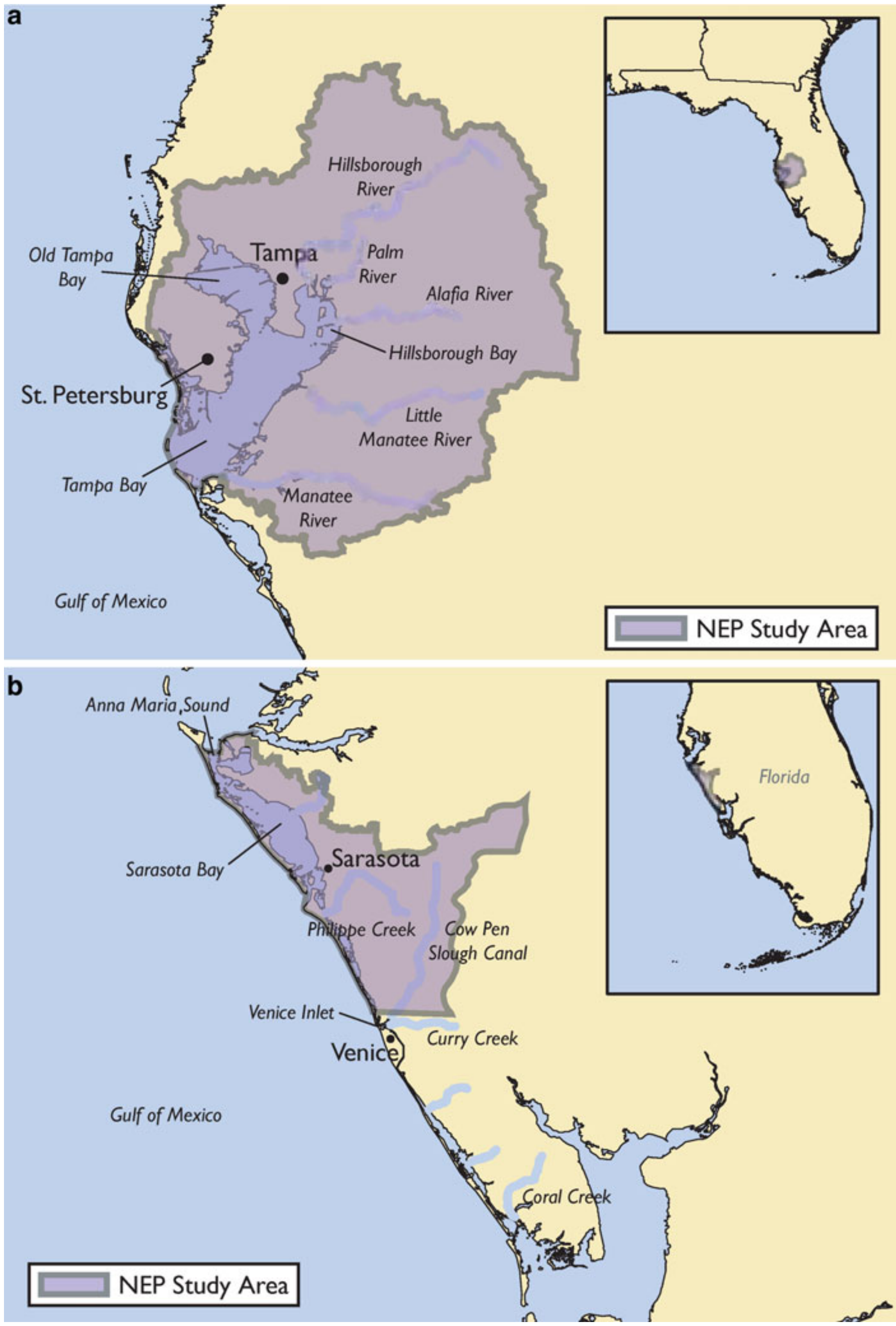

Figure 2.40. Maps of (a) Tampa Bay and (b) Sarasota Bay (modified from USEPA 2006).

and Manatee rivers. The Intracoastal Waterway empties into the bay via Boca Ciega Bay and into the Gulf of Mexico via the Southwest Channel and Passage Key Inlet. Sarasota Bay, located on the southwestern coast of Florida, covers approximately 135 km^2 (52 mi^2) of surface water area and is a small, subtropical estuary (Figure 2.40b). The bay's watershed includes Manatee and Sarasota counties and covers approximately 389 km^2 (150 mi^2) of land. The bay extends from Venice Inlet to Anna Maria Island including the barrier islands and the mainland

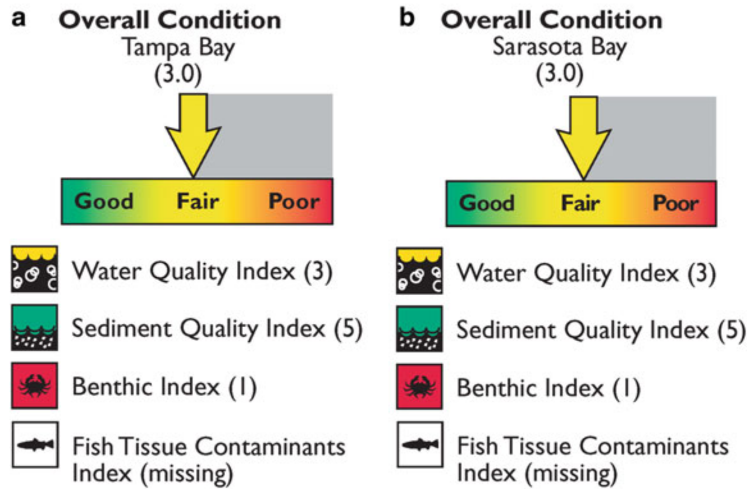

Figure 2.41. Overall condition of (a) Tampa Bay and (b) Sarasota Bay in 2000 (modified from USEPA 2006).

east to Interstate 75 (SJRWMD 2002). Sarasota Bay was classified as an Outstanding Florida Water Body and an Estuary of National Significance in 1987 (SBNEP 2000; FDEP 2005). Sarasota Bay is the largest and deepest bay between Tampa Bay and Charlotte Harbor. The bay is flushed by passes (Big Sarasota, New, and Longboat) making its waters much clearer than those of smaller bays to the south (Roberts, Little Sarasota, and Blackburn bays) (Florida Center for Community Design and Research 2004). Over the years, Sarasota Bay's water quality has improved due to the provision of more freshwater from the surrounding watershed. Most of the bay's estuarine areas are designated as recreational-use waters for fishing and swimming. Sarasota Bay's watershed is highly urbanized.

The overall condition and the water quality index for Tampa Bay and Sarasota Bay were rated fair in 2000 (Figures 2.41 and 2.43; Table 2.6). A summary of the percentage of estuarine area of each bay rated good, fair, poor, or missing for each parameter of the water quality index is provided in Figure 2.42. This assessment was based on data collected in 2000 from 25 to 20 locations sampled in Tampa Bay and Sarasota Bay, respectively (Figure 2.43).

Comparing NOAA's Estuarine Eutrophication Survey (NOAA 1997) and results from the 2000 survey (USEPA 2006) some improvements were noted. Nitrogen was a major pollutant of concern for Florida's bays. In Sarasota Bay nitrogen was being transported to the bay by base flow, wastewater, stormwater, and atmospheric deposition (SBNEP 2000). Atmospheric deposition of total nitrogen to the surface of Tampa Bay accounted for about one-quarter of the nitrogen loading (about 707 metric tons or 780 tons per year) (Poor et al. 2001). This did not include deposition of nitrogen in the watershed washed into the estuary by stormwater. When both direct and indirect pathways were considered, more than 50 % of the total nitrogen loading to Tampa Bay originated from atmospheric sources, while only 15 % of total nitrogen loading was derived from atmospheric deposition in Sarasota Bay (Poe et al. 2005) (Figure 2.44).

In Sarasota Bay, human activities such as management of waste and the operation of automobiles and watercraft contributed a much larger fraction of nitrogen and other contaminants that degrade water quality than did base flow and atmospheric sources (Figure 2.44). Increased development had resulted in excess nitrogen pollution and stormwater runoff into Sarasota Bay. Stormwater and suspended matter were transported into Sarasota Bay by tributaries resulting in the poorest water quality. Overall water quality monitoring data showed improvements in Tampa and Sarasota Bay. In Tampa Bay, estimates showed that nitrogen

Table 2.6. Comparison of Water Quality Indicators between 1997 and 2000 in Tampa Bay and Sarasota Bay (modified from NOAA 1997 and USEPA 2006)

Water quality indicator	NOAA 1997[a]		USEPA 2006 (percentages of area)	
	Tampa Bay	Sarasota Bay	Tampa Bay	Sarasota Bay
Water quality index	NA	NA	Fair	Fair
Chlorophyll *a* concentrations	Med./V. High	High	Overall fair	Overall fair
			Good 32 %	Good 20 %
			Fair 52 %	Fair 75 %
			Poor 16 %	Poor 5 %
DIN concentrations	Med./High	Med.	Overall low (good)	Overall low (100 % good)
DIP concentrations	Med./High	High	Overall fair	Overall fair
			Good 16 %	Good 75 %
			Fair 72 %	Fair 10 %
			Poor 12 %	Poor 15 %
Water clarity	NA	NA	Overall poor	Overall fair
			Good 36 %	Good 15 %
			Fair 36 %	Fair 65 %
			Poor 28 %	Poor 10 %
Dissolved oxygen	NA	NA	Overall good	Overall fair
			Good 88 %	Good 80 %
			Fair 12 %	Fair 15 %
			Poor 0 %	Poor 5 %

[a]*NA* not applicable, *Med.* medium, *V. High* very high

loading for 1995–2003 was higher than for 1985–1994 mostly due to rains and runoff associated with an El Niño event in 1997–1998 (Poe et al. 2005). In Sarasota Bay, data for 1968–1991 indicates that nutrient and chlorophyll *a* levels were decreasing in the bay. Data for 1980–2002 suggests that DIN and chlorophyll *a* concentrations had declined over the long term in Sarasota Bay. Inorganic phosphorus levels also declined, but increases were noted in some years (Dixon 2003). In general, trends across Sarasota Bay are the same, though there were differences in the magnitude of the changes depending on location within the bay, especially areas receiving water from tributaries. Occasionally elevated levels of bacteria in Tampa Bay waters were detected most likely due to septic system malfunctions and stormwater runoff during rainfall events. Bacteria levels were seen as a potential public health concern for recreational swimming and boating activities. In 2000, a survey showed that the human health risk from bacterial contamination was low throughout Tampa Bay with only 2 of 22 locations exceeding guidelines for human health (Rose et al. 2001).

2.3.7 Coastal Water Quality and Petroleum

Coastal regions are the locations where most chemical contaminants are used and released to the environment, and nearshore environments are also the sites of delivery of land-derived chemical inputs via river- and precipitation-associated runoff and atmospheric deposition. Therefore, if chemical contaminants play a significant role in degrading water quality, they

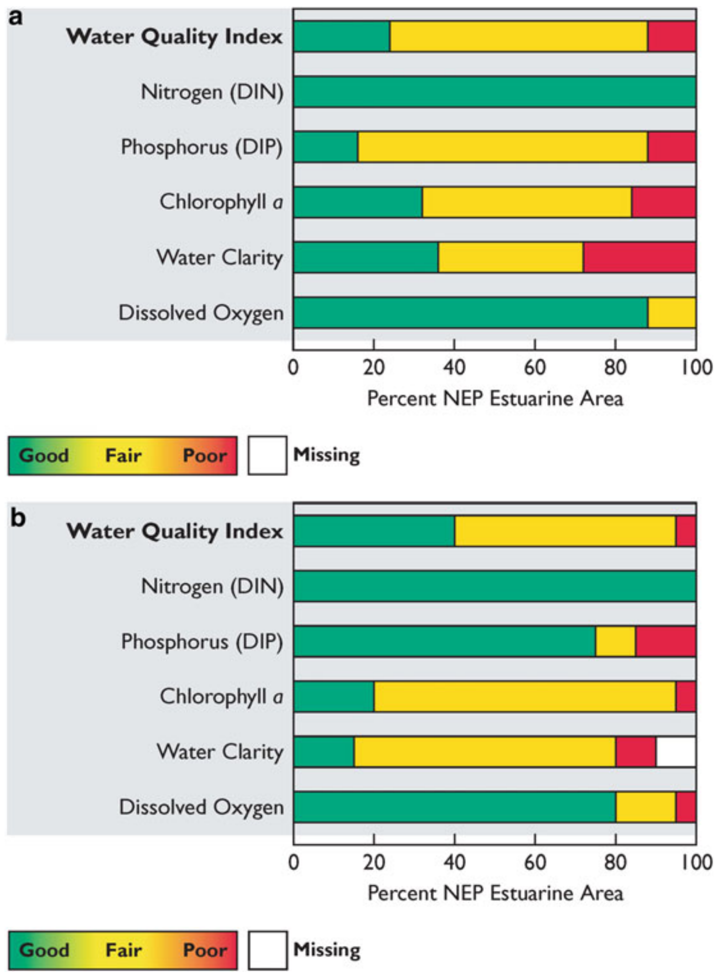

Figure 2.42. Percentage of estuarine area achieving each rating for the water quality index and its components (a) Tampa Bay and (b) Sarasota Bay (modified from USEPA 2006).

are most likely to be detectable in coastal water bodies, with an exception being the immediate effects of large volume oil releases in offshore regions (e.g., spills). As discussed, few water quality assessment studies directly measure chemical concentrations in water due to the low concentrations, so other approaches must be used to assess the role of chemical contaminants in degrading water quality. Two approaches to assessments were described in the introduction. One approach considers the mass loadings of contaminants to receiving water bodies, and the second considers the detection of contaminants in lipid-rich organismal tissues that preferentially accumulate, and in some instances magnify, chemical contamination. As described in the introduction, chemical contaminants can be classified as petroleum or non-petroleum with the latter category subdivided into organic and inorganic non-petroleum contaminants (for detailed descriptions of contaminants in these categories see the introduction and Appendices B and C). As noted, these categories of chemical contaminants have different sources, environmental fates, and toxicities and thus different potentials for affecting water quality. The most comprehensive analysis of annual mass loadings of contaminants to the northern Gulf of Mexico is available for petroleum. The NRC's *Oil in the Sea III*: *Inputs*, *Fates*, *and Effects* report (NRC 2003) summarizes annual mass loadings in the coastal northern Gulf of Mexico

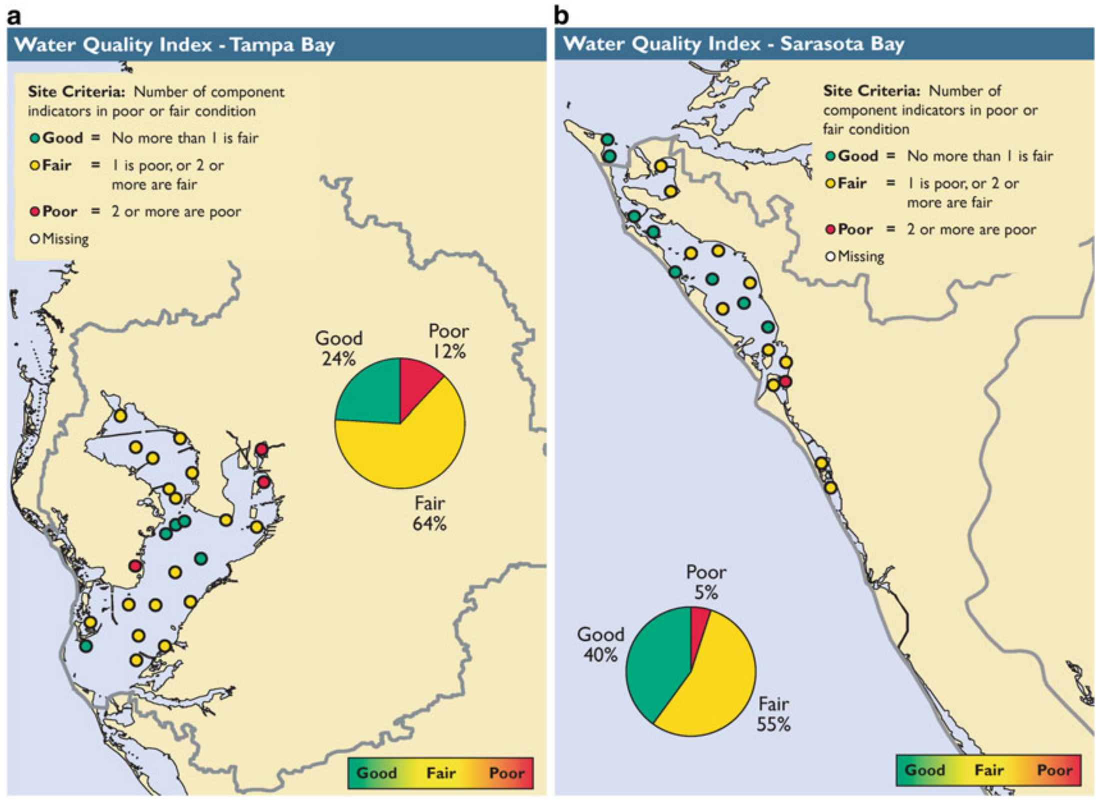

Figure 2.43. Water quality index data for (a) Tampa Bay and (b) Sarasota Bay in 2000 (modified from USEPA 2006).

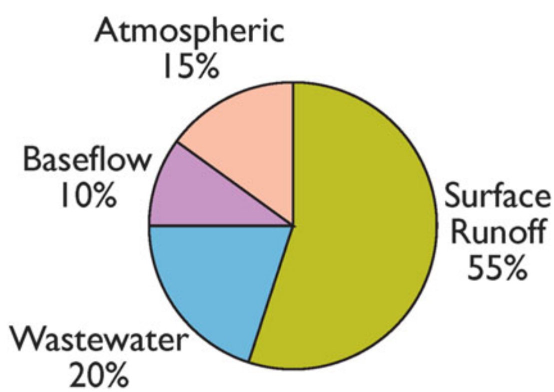

Figure 2.44. Nitrogen distributed (%) in Sarasota Bay in 2000 (modified from USEPA 2006).

for petroleum for 1990–1999. While the report was issued several years ago and the data is from the 1990s, these 9-year average mass loadings are indicative of longer-term trends regarding the role of petroleum contamination in degrading water quality. While the absolute amounts associated with specific releases will vary with time, the NRC report estimates are within the time frame of assessments of coastal water quality conditions along the northern Gulf of Mexico covered in this review. Therefore, the trends identified in coastal water quality can be compared and contrasted, at least qualitatively, with the trends discerned from petroleum mass

Table 2.7. Average Annual Mass Loadings of Petroleum (tonnes) to the Coastal Gulf of Mexico from 1990 to 1999 (1 tonne = 1 metric ton(ne) = 1.102 U.S. short tons) (modified from NRC 2003)

Zone (coastal)	North Central/ Northeastern	North Central/ Northwestern	South Central/ Southwestern
Sum seeps[a]	*na*	*na*	*na*
Platforms	Trace[b]	90	nd[c]
Atmospheric	Trace	trace	nd[c]
Produce	Trace	590	Trace
Sum extraction	*Trace*	*680*	*Trace*[c]
Pipelines	Trace	890	Trace
Tank vessel	140	770	80
Coastal facilities	10	740	nd[d]
Atmospheric	Trace	Trace	Trace
Sum transportation	*160*	*2,400*	*90*
Land-based	1,600	11,000	1,600
Recreational vessels	770	770	nd[e]
Vessels > 100 gigatonne (spills)	30	100	Trace
Vessels > 100 gigatonne (op discharge)	Trace	Trace	Trace
Vessels < 100 gigatonne (op discharge)	Trace	Trace	Trace
Atmospheric	60	90	100
Aircraft[f]	na	na	na
Sum consumption	*2,500*	*12,000*	*1,700*

[a]No known seeps in these regions
[b]Estimated loads of less than 10 tonnes per year reported as "trace"
[c]Lack of precise locations for platforms in this zone precluded determining whether spills or other releases occurred less than 3 mi from shore, thus all values for this zone reported as "offshore"
[d]No information on the existence of coastal facilities was available for this region
[e]Populations of recreational vessels were not available for these regions
[f]Purposeful jettisoning of fuel not allowed within 3 mi of land

loadings. The NRC report also assesses petroleum inputs to other North American coastal waters, providing useful comparisons with Gulf of Mexico estimates. Much of the oil and gas production in North America is located in the Gulf of Mexico, so conclusions about petroleum contamination in North American marine environments are largely applicable to the Gulf of Mexico. The following assessment is constrained by the limitations to this approach discussed in the introduction (e.g., mass loadings reflect the intensity and location of petroleum usage but do not directly indicate biological or ecological impact or ambient water concentrations). This review provides comprehensive information about the sources, geographic distributions, and magnitude of petroleum contamination of the northern coastal Gulf of Mexico for completeness. Mass loadings of average annual petroleum inputs to the coastal Gulf of Mexico for 1990–1999 are summarized in Table 2.7 (NRC 2003).

The other categories of chemical contaminants also have the potential to impact water quality. However, there are no summaries of mass loadings for these contaminants similar to those provided by the NRC (2003) report for petroleum. In order to assess the potential impact of these other contaminants on water quality, the second approach described in the introduction—using data on the presence of contaminants in biological tissues—is employed.

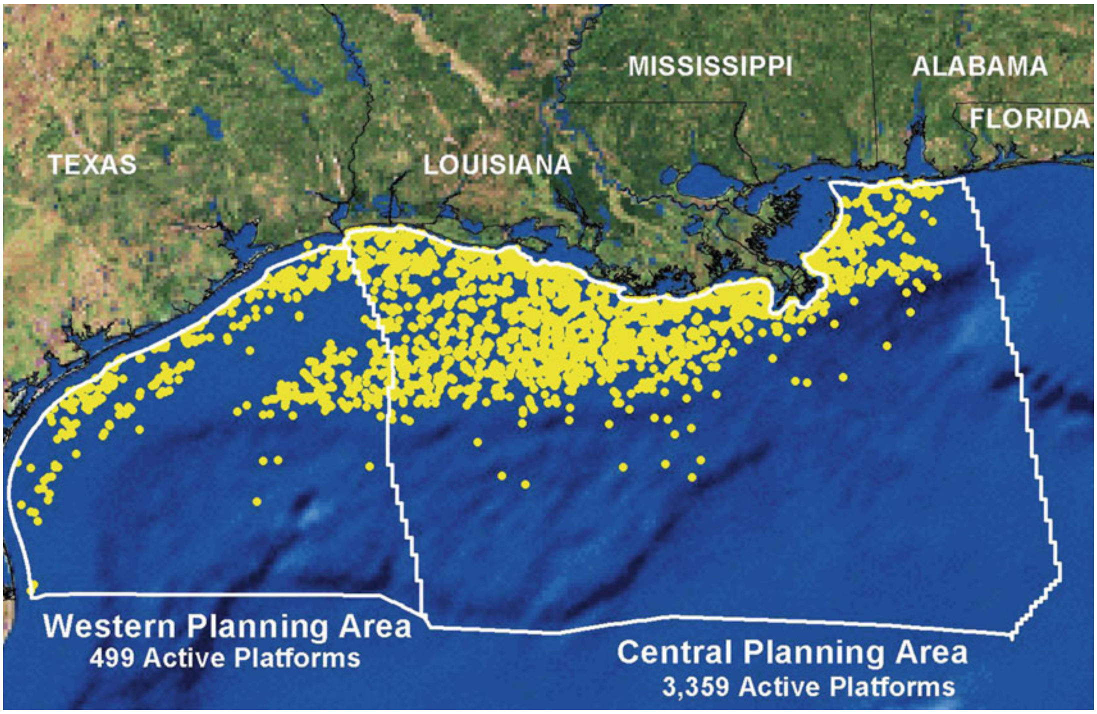

Figure 2.45. Map of the 3,858 oil and gas platforms in the Gulf of Mexico in 2006. The size of the dots used to note platform locations is highly exaggerated and the density of platforms is low (from NOAA 2012).

This qualitative indication of the role of contaminants in degrading of coastal water quality is considered in Section 2.3.8. The detection of petroleum in biological tissue is also reported in the national coastal assessments.

The Gulf of Mexico is one of the most prolific oil and gas provinces in the world and has been the site of oil and gas exploration and extraction activities for many decades. In 2006, there were nearly 4,000 oil and gas platforms in the northern Gulf of Mexico, mostly offshore of Louisiana and Texas (Figures 2.45 and 2.46). In recent years, new oil and gas exploration and production in the Gulf of Mexico has been concentrated on the continental shelf/slope and deeper water regions, but there is a long history of these activities in coastal waters and adjacent onshore areas (Figures 2.45 and 2.46). Activities associated with the transportation and consumption of petroleum are widespread in the Gulf of Mexico as well (Figure 2.47). Large petrochemical and refining complexes are located along the Texas coast making the Gulf of Mexico a major destination for seaborne and pipeline transportation of petroleum and refined products (NRC 2003). The widespread extraction, transportation, and consumption of petroleum in the northern Gulf of Mexico have resulted in chronic releases of petroleum to the environment for many years. In addition, major river systems, including the Mississippi River, deliver petroleum contaminants via runoff from the land. Adding to these anthropogenic sources of petroleum, the Gulf of Mexico is also the location of extensive natural oil and gas seepage (Figure 2.48). Once released to the environment, by whichever pathway, petroleum poses a range of environmental threats including the potential to degrade water quality. Beyond the more directly observable physical impacts, the toxicity of compounds that make up petroleum can affect organisms from the cellular to the population level (NRC 2003). Compounds that occur in petroleum, such as PAHs, are also known human carcinogens. Once weathered and

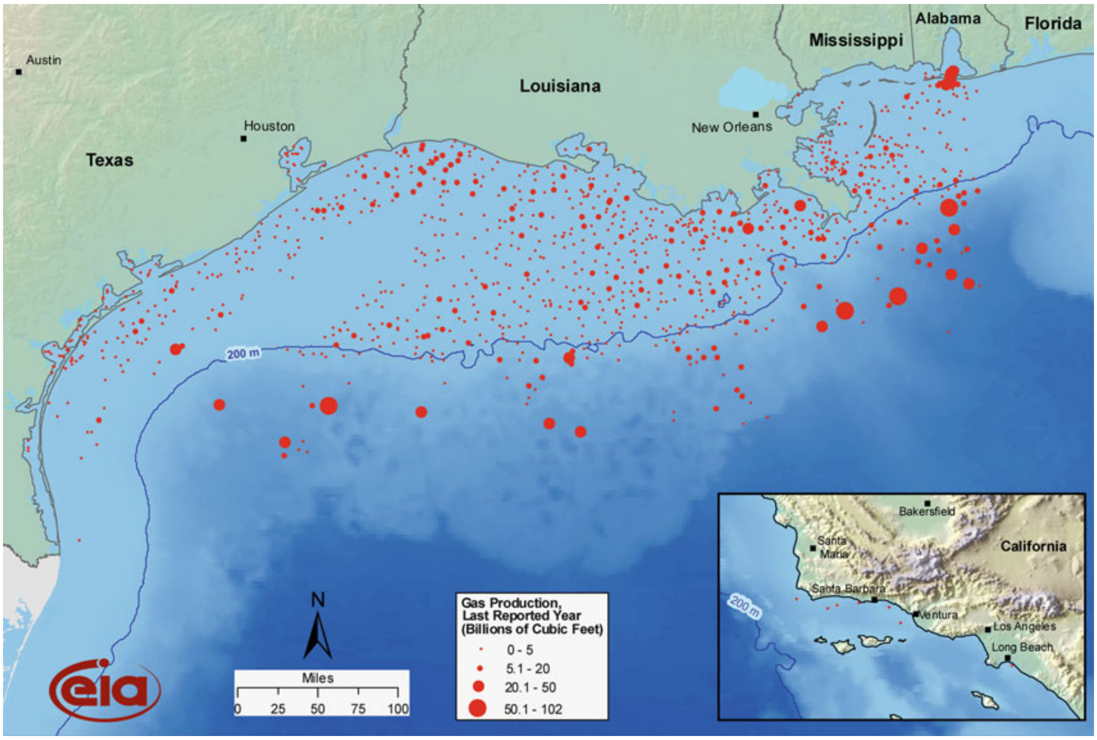

Figure 2.46. Offshore gas production in the Gulf of Mexico (from Energy Information Administration 2009).

mixed with particulate matter, oil in the environment often forms tar balls that float or, if dense enough, can sink to the sea floor. Floating tar balls are found throughout the Gulf of Mexico and can have direct effects on organisms due to uptake in diets or by adherence to surfaces of organisms. In general, tar balls are not expected to be a major factor in degrading water quality, but they are widely detected in marine environments, and the Gulf of Mexico is no exception.

2.3.7.1 Natural Oil and Gas Seeps

The seepage of oil and gas in marine environments is a natural phenomenon that occurs when oil and gas from deep subsea reservoirs migrate to surface seafloor sediments and into the overlying water column. Natural seepage of oil into the marine environment is the largest source of petroleum to the marine environment (NRC 2003). Annual releases due to oil and gas seeps are estimated to exceed 160,000 tonnes (176,000 tons) in North America alone, accounting for over 60 % of the petroleum entering marine waters (Figure 2.49). Almost all deeply buried petroleum reservoirs naturally leak to some extent, and marine environments overlying prolific oil and gas provinces, such as the northern Gulf of Mexico, are chronically subjected to natural oil and gas seepage. The effects of oil and gas seepage are generally restricted to closely associated sediments and benthic organisms and the formation of oil slicks at the air/sea interface. However, seeping oil and gas transits through the water column and aerobic microbial oxidation of hydrocarbons consumes oxygen. Gaseous and low molecular weight hydrocarbons dissolve in seawater based on their solubility, the temperature and salinity of the water, and the time in contact with water. The water column directly above oil and gas seeps can exhibit lowered oxygen concentrations due to aerobic microbial degradation of petroleum. In general, due to the well-mixed nature of marine waters these effects are restricted to a few meters or less up into the water column above the sediment/water interface. Hydrocarbon gases (e.g., methane, ethane, propane and butane) are more soluble in water than liquid hydrocarbons and more buoyant and often form plumes that can persist into the water column meters above seep locations and even reach the sea surface. Petroleum seeps in the Gulf of Mexico occur mostly in deeper water offshore regions and are discussed in more detail in the section on offshore water quality (Figure 2.48). In the coastal Gulf of Mexico few oil and gas seeps have been observed so natural oil seepage in this region is considered to be a negligible source of petroleum contamination, suggesting that this source of petroleum has an insignificant effect on coastal water quality (Table 2.7).

a

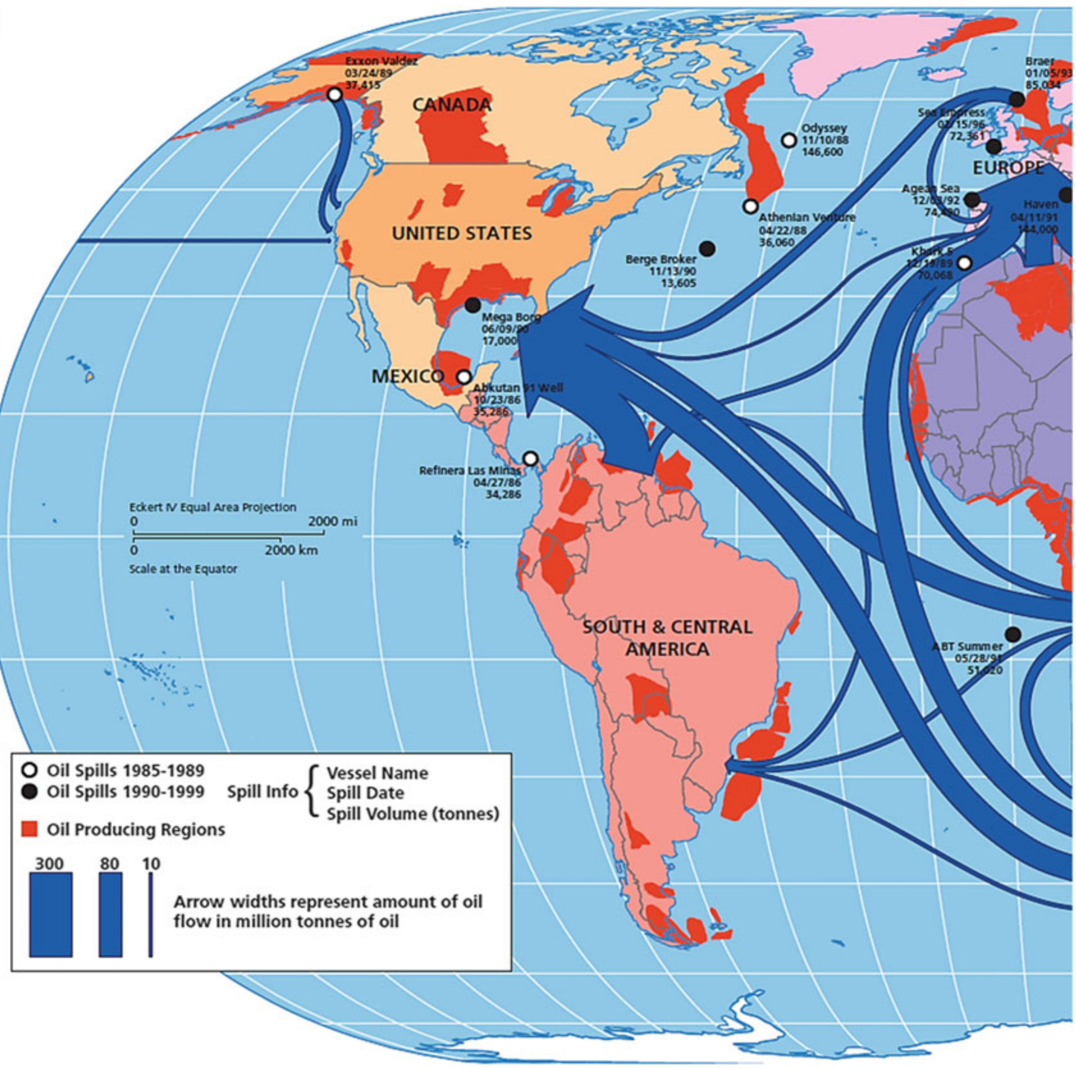

Figure 2.47. Worldwide seaborne flow of oil in 2000 in millions of tonnes (modified from NRC 2003).

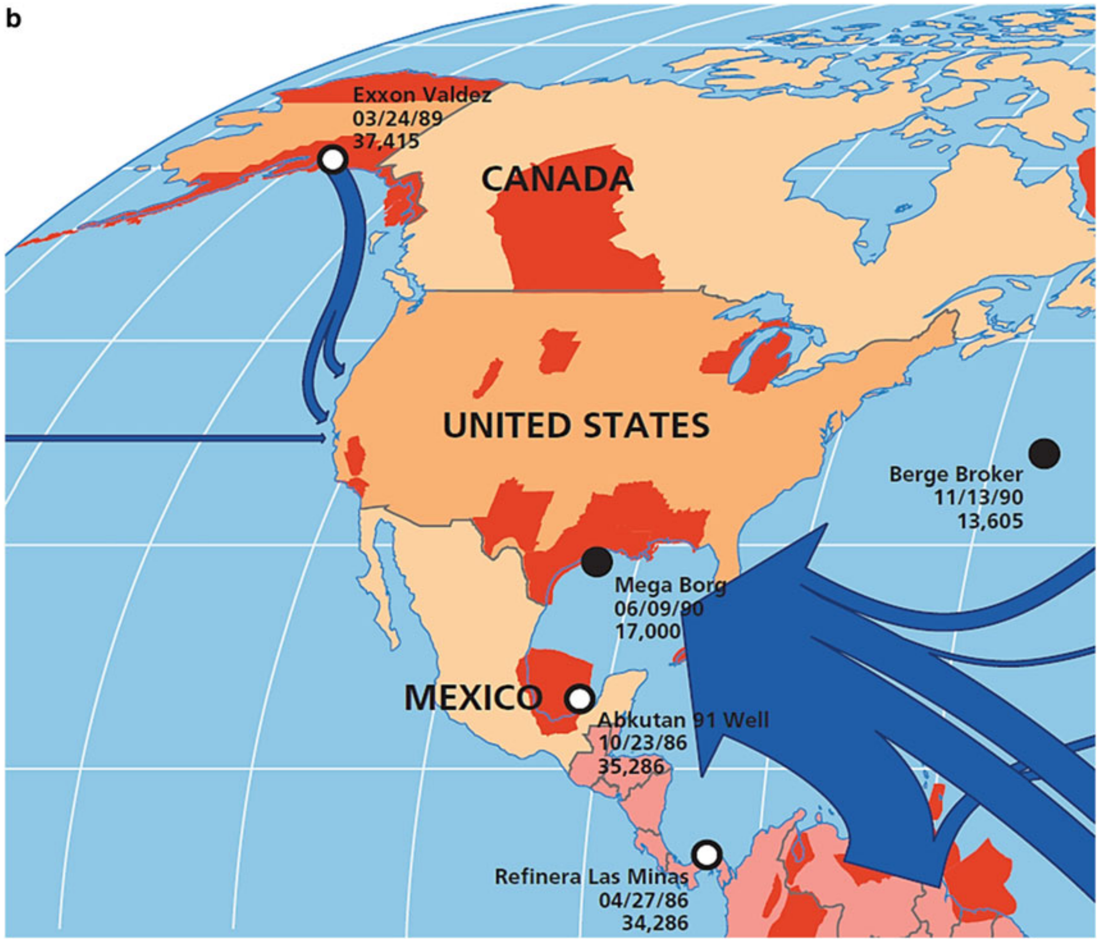

Figure 2.47. (continued)

2.3.7.2 Extraction of Petroleum

Extraction of oil and gas is a source of spills and other releases to the marine environments (NRC 2003). Extraction activities release petroleum and refined products to the surrounding water from platforms by discharging produced waters and by atmospheric releases and deposition (Figure 2.49) (NRC 2003). The nature and size of these releases are highly variable from site to site. Activities associated with oil and gas exploration or production introduced on average approximately 3,000 tonnes (3,307 tons) of petroleum to North American waters each year for the 1990–1999 time period, and annual totals for the coastal Gulf of Mexico were estimated at 680 tonnes (750 tons), almost all in the northwestern region (Table 2.7; Figures 2.49 and 2.50). Inputs from platforms can occur as spills or as chronic releases. For comparison, it was estimated that the IXTOC-I blowout released 476,000 tonnes (524,700 tons) of petroleum to the Gulf of Mexico over approximately 9 months in 1979 (NRC 2003). For the 1990–1999 time period, an estimated 150 tonnes (165 tons) of petroleum per year was accidentally spilled from platforms in North American waters (NRC 2003). The use of chemical dispersants on oil spills can materially change the behavior of oil in seawater.

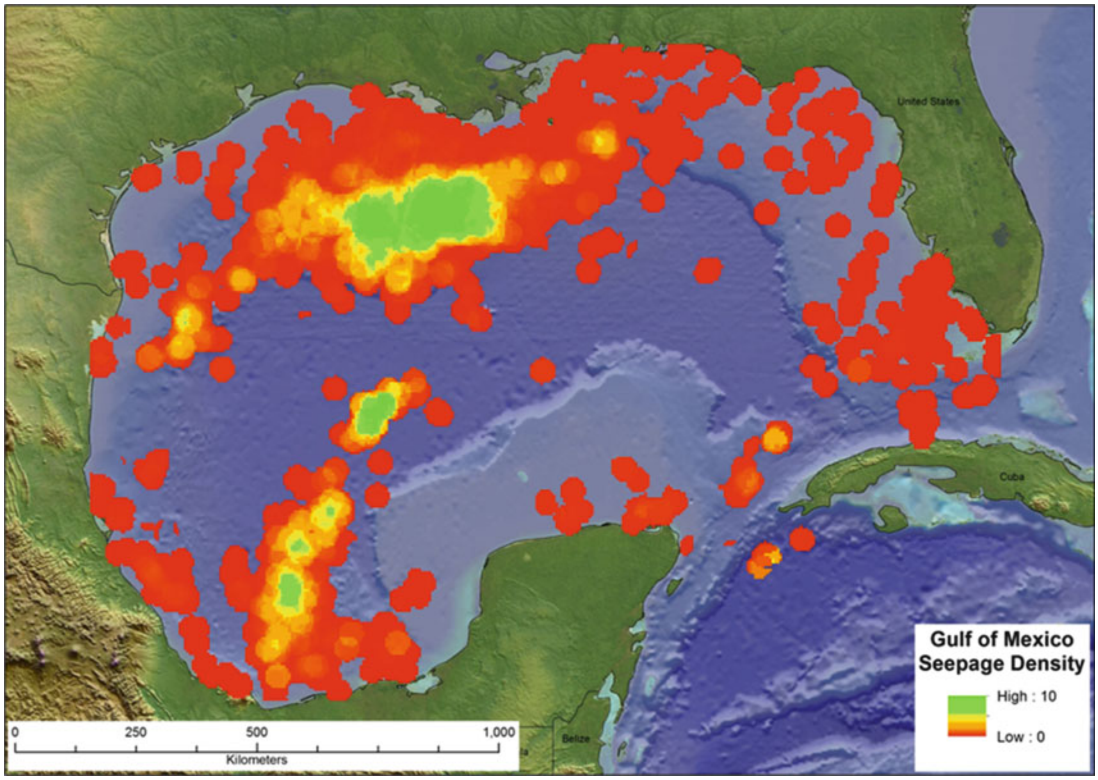

Figure 2.48. Oil and gas seepage in the Gulf of Mexico (determined from analysis of synthetic aperture radar, graphic provided by CGG's NPA Satellite Mapping, used with permission).

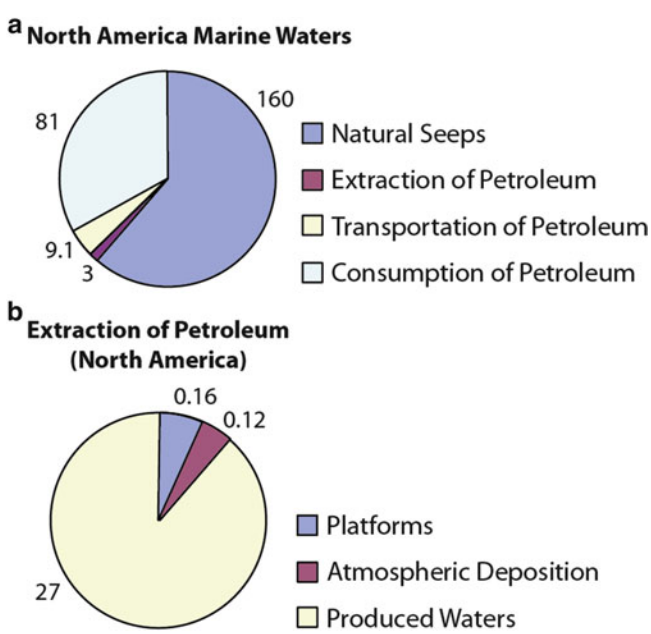

Figure 2.49. Average annual releases of petroleum hydrocarbons in thousands of tonnes (1 tonne = 1 metric ton(ne) = 1.102 U.S. short tons) to North American waters from (a) natural seeps and extraction, transportation, and consumption activities and (b) petroleum extraction from 1990 to 1999 (modified from NRC 2003).

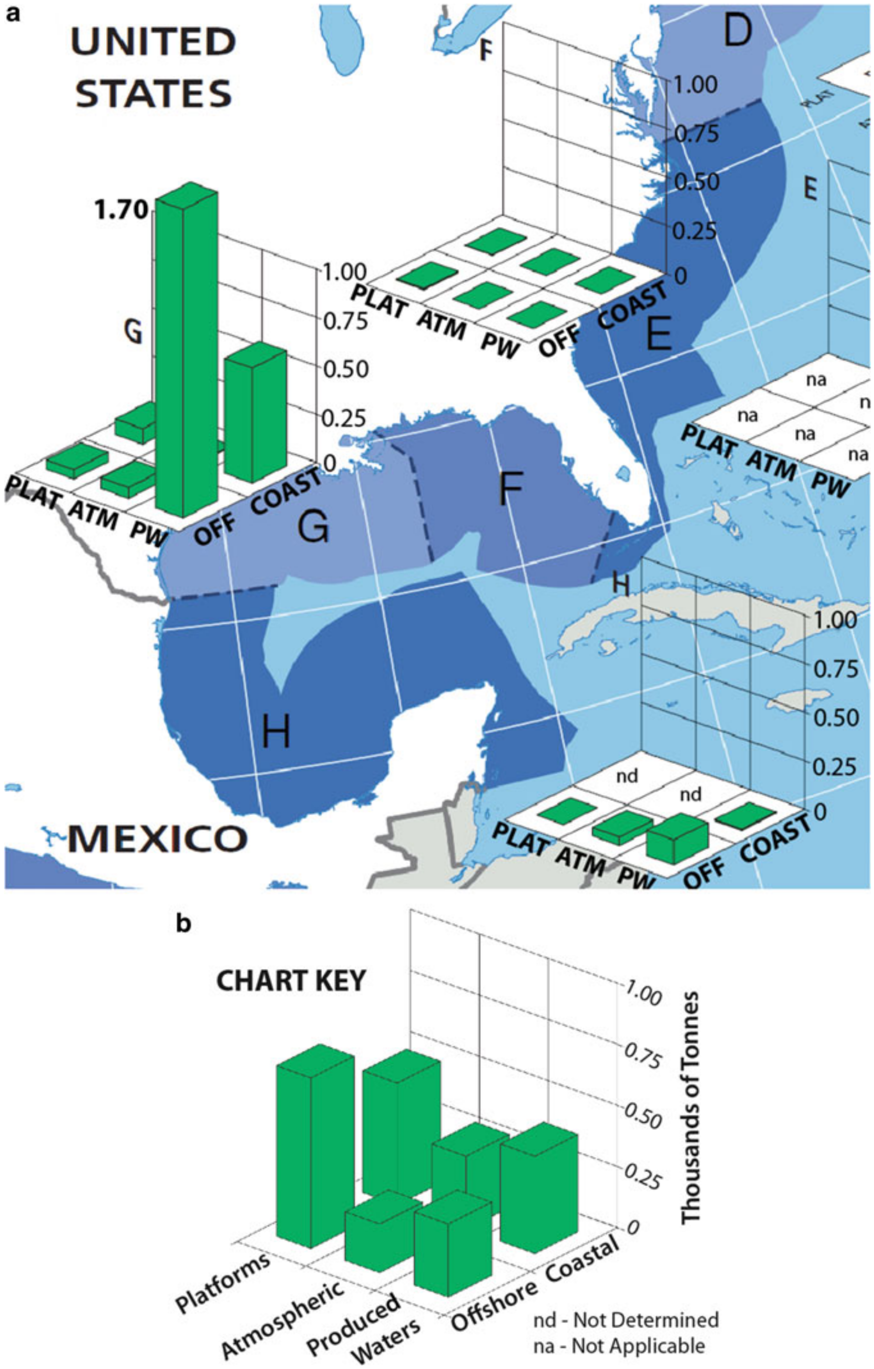

Figure 2.50. Average annual input of petroleum hydrocarbons in thousands of tonnes to the Gulf of Mexico from petroleum extraction for 1990–1999 (modified from NRC 2003).

2.3.7.3 Transportation of Petroleum

The transportation of petroleum releases varying amounts of petroleum from major spills to small regular operational releases. Petroleum hydrocarbon discharges into marine waters by transportation activities include pipeline spills, tank vessel spills, discharges from cargo

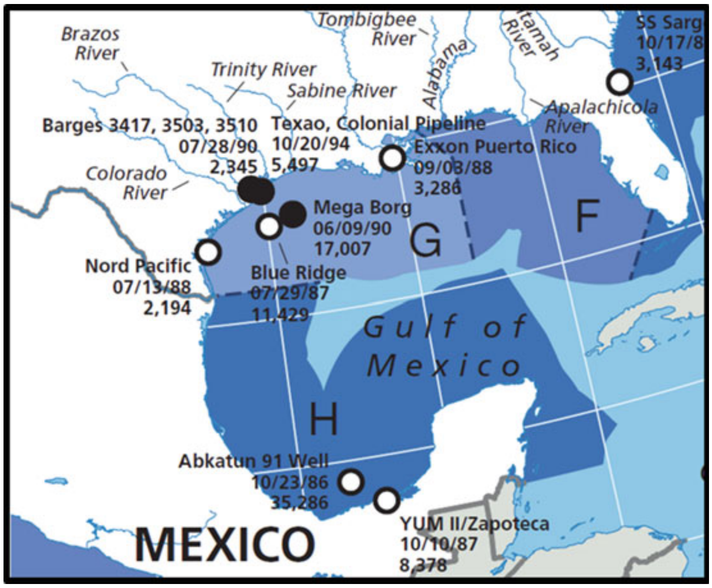

Figure 2.51. Distribution of selected vessel oil spills in the Gulf of Mexico in tonnes (*solid black dots* indicate spills included in the average annual mass loadings from 1990 to 1999 (modified from NRC 2003).

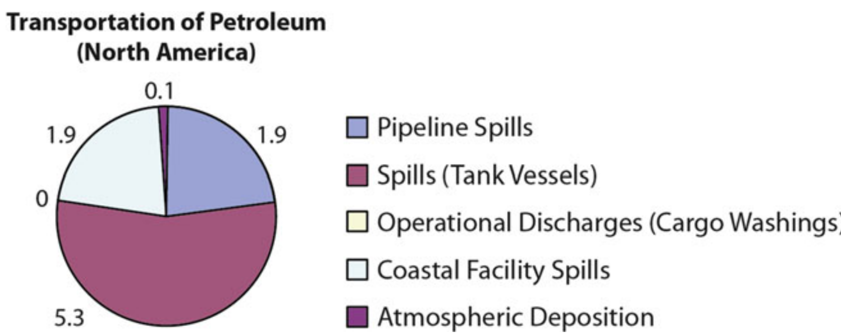

Figure 2.52. Average annual input of petroleum hydrocarbons in thousands of tonnes to North American marine environments from the transport of petroleum for 1990–1999 (modified from NRC 2003).

washings, spills at coastal facilities, and atmospheric deposition of releases from tankers (Figure 2.51) (NRC 2003). Transportation, including refining and distribution activities, of petroleum or refined products resulted in the release, on average, of 9,100 tonnes (10,031 tons) per year of petroleum to the marine environments of North America for 1990–1999 (Figure 2.52) (NRC 2003). From 1990 to 1999, total annual mass loading of petroleum from transportation activities for the coastal northwestern and northeastern Gulf Mexico were 2,400 tonnes (2,646 tons) and 160 tonnes (176 tons), respectively (Table 2.7). In the northwestern Gulf of Mexico the releases from pipelines, tank vessels, and coastal facilities were similar in magnitude, whereas in the northeastern Gulf of Mexico releases came almost exclusively from tank vessels (Table 2.7). Atmospheric deposition was considered negligible in both regions during this time period. Pipeline spills can occur as petroleum is transported from the source to refineries and from refineries to the consumer (NRC 2003). Tank vessels are allowed discharges of contaminated water related to cargo and propulsion machinery whereas non-tankers are only allowed machinery-related discharges (NRC 2003). Operational discharges from cargo washings are illegal in North American coastal waters (NRC 2003). Discharges of oil in ballast and tank washing from oil tankers are prohibited within 92.6 km (50 nautical miles) of the coast (NRC 2003). Discharges from coastal facilities include episodic spills as well as chronic releases (NRC 2003).

Releases due to the transportation of petroleum were approximately 9 % of the total petroleum input to the marine environments of North America during this time period. Most transportation-related releases of petroleum occurred in the western Gulf of Mexico where the majority of offshore platforms, pipelines, coastal oil refineries and chemical plants, and major ports are located (Figure 2.53). A major source of petroleum released to the Gulf of Mexico during the extraction process is the intentional discharge of produced waters (Figure 2.49b). Over 90 % (2,700 tonnes; 2,976 tons) of petroleum released during extraction activities during 1990–1999 was accounted for by produced water discharges which release low but continuous amounts of dissolved components and dispersed crude oil to the marine environment. Discharges of produced water have the potential to impact water quality across the northern Gulf of Mexico given the large number and density of petroleum platforms offshore Louisiana and Texas (Figure 2.45). The potential for impact from discharged waters is greatest in coastal or inland areas where flushing rates are low and petroleum tends to accumulate over time. Shallow water areas with restricted flow and dispersion (low flushing rates), water with a high concentration of suspended particulates, and fine-grained anaerobic sediments are especially vulnerable to water quality issues (Boesch and Rabalais 1989a, b; St. Pé KM 1990). In the Gulf of Mexico, coastal oil production occurs only in Louisiana and Texas. In the late 1990s the discharge of produced water in coastal waters was prohibited so this input has been greatly reduced since then (Boesch and Rabalais 1989a, b; St. Pé KM 1990; Rabalais et al. 1991).

Spills of petroleum associated with platforms accounted for approximately 5 % of the total inputs from extraction activities totaling 2.2–2.5 tonnes (2.4–2.8 tons) and 81 tonnes (89 tons) per year for 1990–1999 in the northeastern and northwestern coastal Gulf of Mexico, respectively, reflecting the low intensity of coastal oil and gas production in the northeastern Gulf of Mexico (NRC 2003). Again, these discharges were prohibited in the late 1990s.

2.3.7.4 Consumption of Petroleum

Once petroleum has been extracted, transported to refineries, and refined, it is delivered to the consumer. The major sources of petroleum releases related to consumption include land-based sources (river discharge and runoff), two-stroke vessel discharges, non-tank vessel spills, operational discharges, atmospheric deposition, and aircraft dumping (Figure 2.54). Consumption-related releases of petroleum are generally individually small; however, the ubiquity and number of releases collectively contribute the majority of anthropogenic petroleum to marine environments (Figure 2.54) (NRC 2003). On average, approximately 84,000 tonnes (92,594 tons) per year of petroleum were released to marine waters of North America for 1990–1999 (NRC 2003). Releases associated with the consumption of petroleum were approximately 70 % of the petroleum released from anthropogenic sources to North American waters during this time period. The majority of the consumption of petroleum occurs on land so together, river and waste and stormwater runoff are the largest sources of petroleum to coastal environments. Another important input of petroleum in coastal areas is leakage from two-stroke engines. Land runoff and two-stroke engines accounted for approximately 75 % of the petroleum introduced to North American waters by petroleum

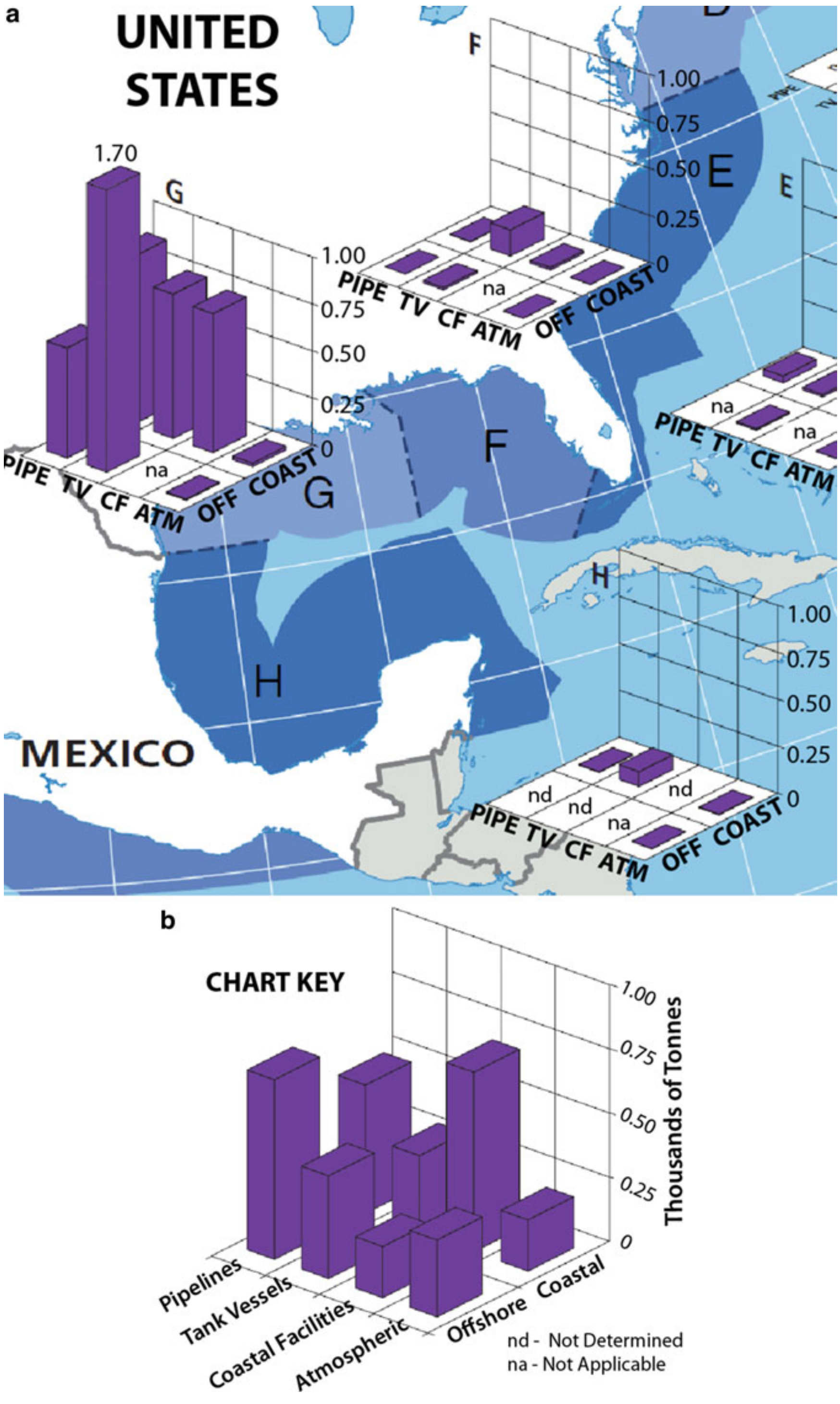

Figure 2.53. Average annual input of petroleum hydrocarbons in thousands of tonnes to the Gulf of Mexico from petroleum transportation from 1990 to 1999; (modified from NRC 2003).

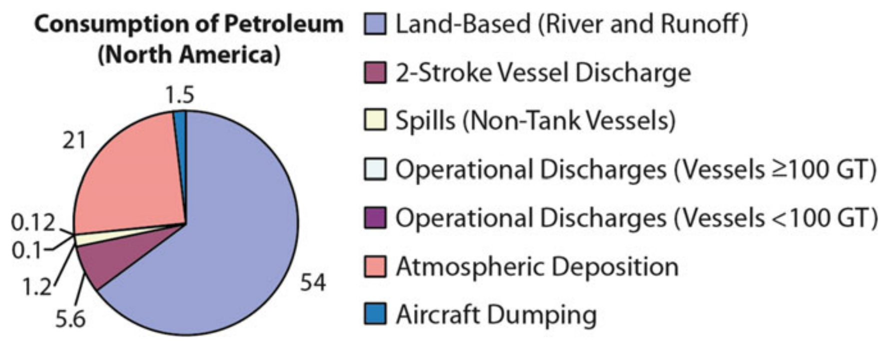

Figure 2.54. Average annual input of petroleum hydrocarbons in thousands of tonnes to North American marine environments from the consumption of petroleum from 1990 to 1999 (modified from NRC 2003).

consumption from 1990 to 1999. These activities are almost exclusively restricted to coastal waters. In the coastal Gulf of Mexico for 1990–1999, annual mass loadings of petroleum from activities associated with consumption were concentrated in the northwestern region and mostly associated with land-based sources (Figure 2.55). For the 1990–1999 time period, land-based sources contributed 12,000 tonnes (13,228 tons) and 1,600 tonnes (1,763 tons) of petroleum annually in the northwestern and northeastern coastal Gulf of Mexico, respectively. The next largest coastal source of petroleum was recreational vessels, which contributed 770 tonnes of petroleum annually to the northeastern and 770 tonnes (849 tons) to the northwestern Gulf of Mexico from 1990 to 1999. All other consumption-related inputs contributed less than 300 tonnes (331 tons) annually to the coastal Gulf of Mexico region for 1990–1999.

2.3.7.5 Spatial Variability of Petroleum Contamination

In summary, coastal northern Gulf of Mexico environments are subject to highly variable mixes of petroleum inputs that differ substantially for the northeastern and northwestern regions (Figure 2.56). For coastal waters, land-based sources of petroleum related to consumption activities are ubiquitous and dominate inputs across the northern Gulf of Mexico. For the 1990–1999 time period, the northwestern Gulf of Mexico received only 21 % of the total input from land-based sources in North America despite the large number of refineries in the region and riverine inflows from the Mississippi River (NRC 2003). However geographic distributions, admixtures of sources, and the magnitude of annual petroleum loadings do reflect the large petroleum industry located in the northwestern Gulf of Mexico that includes all phases of exploration, production and transportation. Transportation-related petroleum mass loadings in the northwestern Gulf of Mexico were about 15–25 times greater than in the northeastern Gulf of Mexico during the 1990s reflecting this concentration of industry (NRC 2003). As noted previously, petroleum contamination is rarely identified as the primary cause of degradation of coastal water quality, except in specific cases such as major oil spills. This is expected, as degraded water quality along the northern Gulf of Mexico has been largely attributed to excess nutrient loadings. Degraded coastal water quality and petroleum contamination in coastal regions are associated with human population patterns as both are predominantly anthropogenic in origin. The ubiquitous presence of petroleum contamination in the northern Gulf of Mexico would be expected to be at least a minor contributor to degraded water quality but these effects are masked by other more dominant factors such as nutrient enrichments.

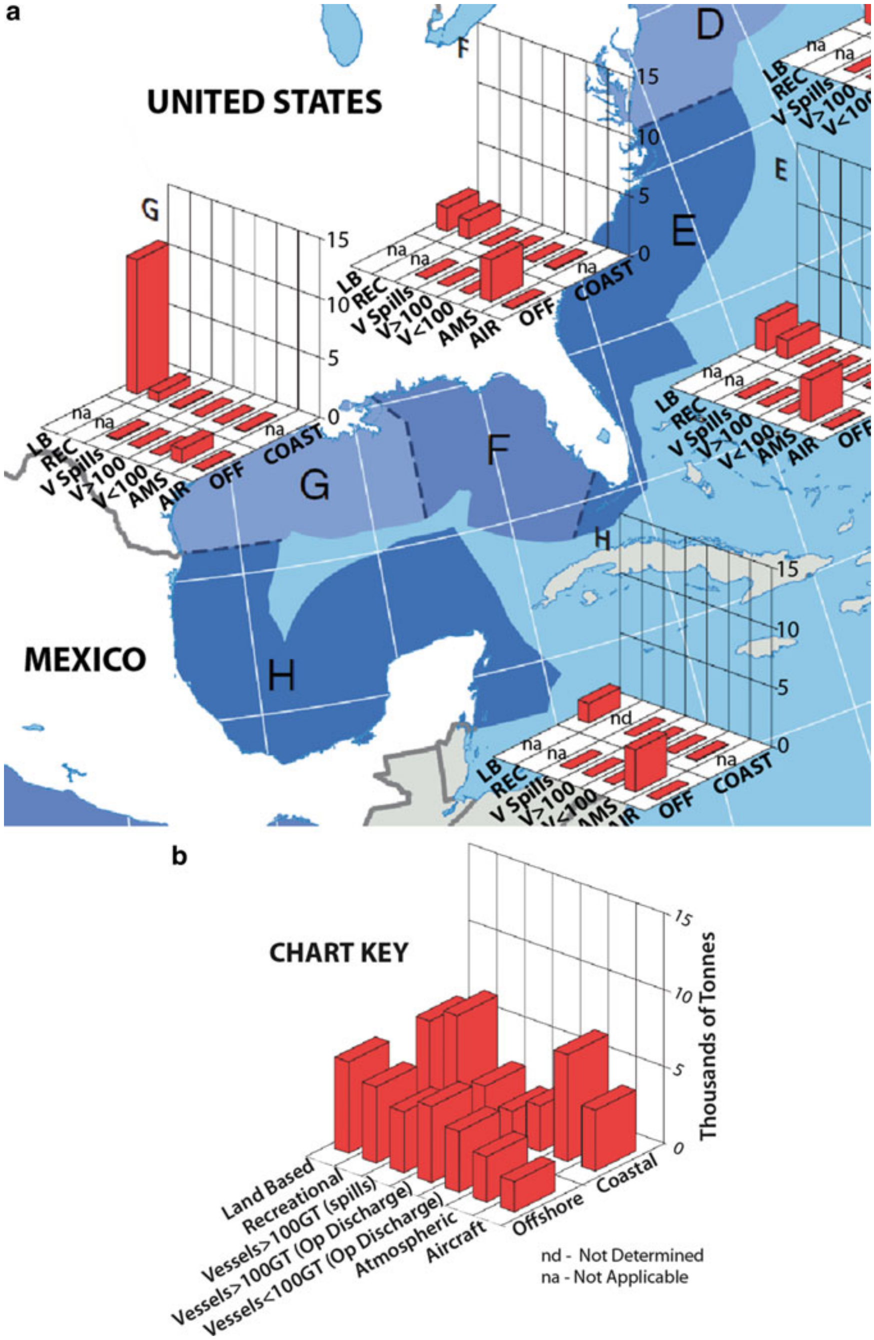

Figure 2.55. Average annual input of petroleum hydrocarbons in thousands of tonnes to the Gulf of Mexico from petroleum consumption for 1990–1999 (modified from NRC 2003).

2.3.8 Coastal Water Quality and Utilization of Water

Water quality is based on the suitability of a body of water for certain uses by ecosystems and/or humans and can be assessed based on how well human expectations are being met in terms of the services provided by a body of water. As described in the introduction, an integration of multiple indicators can be used to assess the impairment of valued activities.

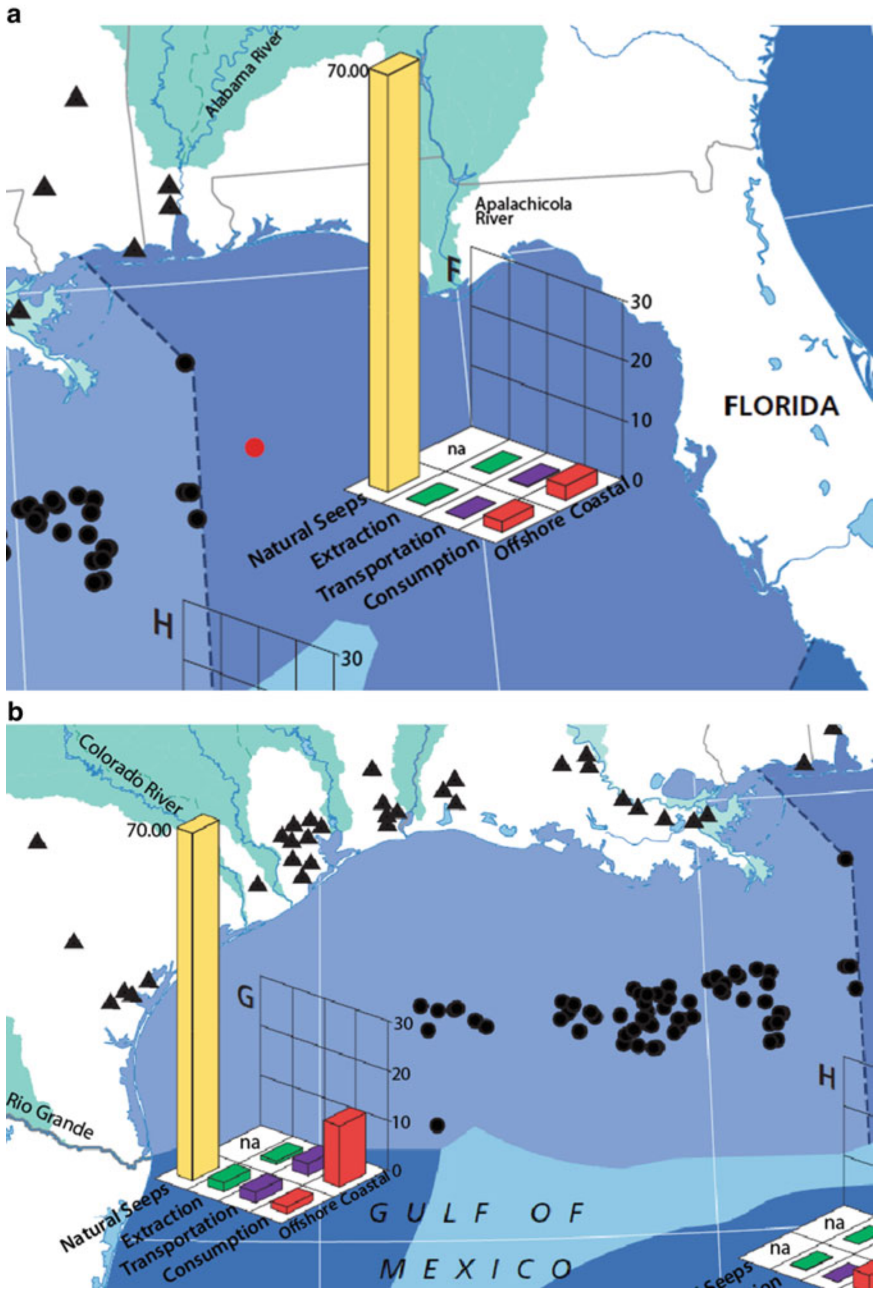

Figure 2.56. Average annual input of petroleum hydrocarbons in thousands of tonnes to the coastal Gulf of Mexico for 1990–1999 (*yellow* = natural seeps, *green* = extraction, *purple* = transportation, and *red* = consumption) (modified from NRC 2003).

Chemical and biological contaminants in water can contribute to impairment by causing acute and/or chronic human health effects, but unambiguous links to degraded water quality are often tenuous. Humans may be exposed to waterborne toxins or pathogens due to consumption of fish and shellfish and/or directly via contact with water. Impacts on ecosystem and human use provide insight into potential issues that might have an origin in water quality. Assessments of impairment also provide an indirect, qualitative assessment of the role of chemical and biological contaminants in degrading water quality within the limitations discussed in the introduction. The following assessments are presented as examples, but an exhaustive review of all information related to water impairment, beach closures and fish consumption reports is beyond the scope of this review as explicit links to water quality are difficult to discern. These examples also provide a qualitative indication of which contaminants may be responsible for impairments and identify hot spots of contamination for comparison with other indicators of water quality.

Based on 5 years of monitoring from 1991 to 1995, 51 % of northern Gulf of Mexico estuaries were assessed as unimpaired, 27 % impaired for human use, and 37 % impaired for aquatic life (percentages add to more than 100 % as estuaries can be impaired for both human and aquatic life use) (Figure 2.57a). For 1996–2000, the overall condition of northern coastal Gulf of Mexico estuaries was rated as fair with 35 % of the estuarine areas assessed as impaired for aquatic life use and 14 % impaired for human use (Figure 2.57b). Of the assessed estuaries, 20 % were in good ecological condition with no evidence of degradation. Of estuarine areas assessed along the northern Gulf of Mexico, 39 % were considered threatened. Gulf States assessed 48 % (18,845 km^2 [7,276 mi^2] of 39,668 km^2 [15,316 mi^2]) of the Gulf Coast estuaries for 1998 Clean Water Act Section 305(b) reports (Figures 2.58 and 2.59). In these reports it was not possible to distinguish between Atlantic Coast and Gulf of Mexico listings, so 305 (b) assessment information for Florida was included in 2001 Gulf of Mexico summaries. Of

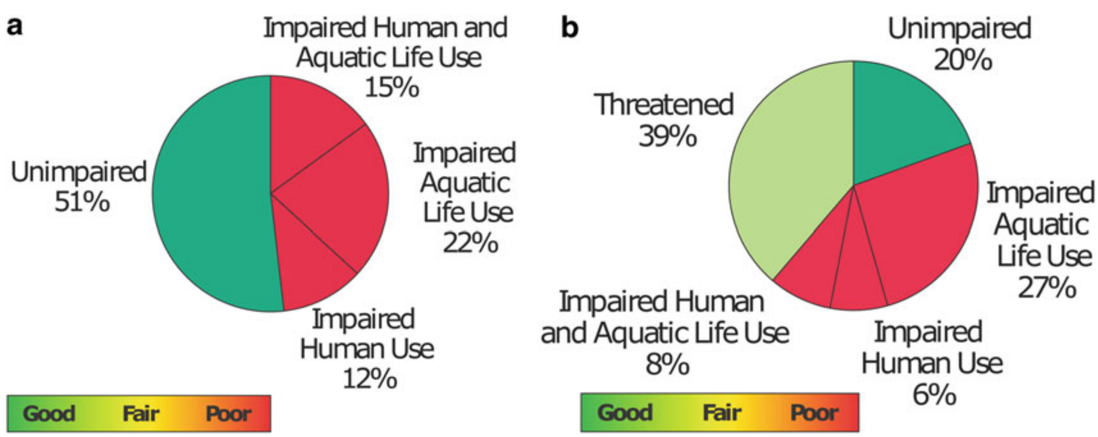

Figure 2.57. Gulf Coast estuarine condition estimates ±6 % based on 5 years of sampling, (a) for years 1991–1995 and (b) for years 1996–2000 (modified from USEPA 2001, 2004).

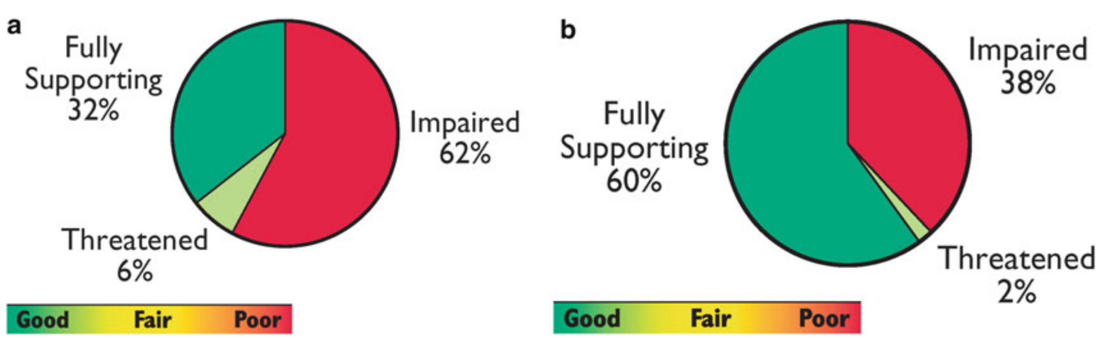

Figure 2.58. Water quality assessments in 1998 for northern Gulf of Mexico (a) estuaries and (b) shore lines (modified from USEPA 2001).

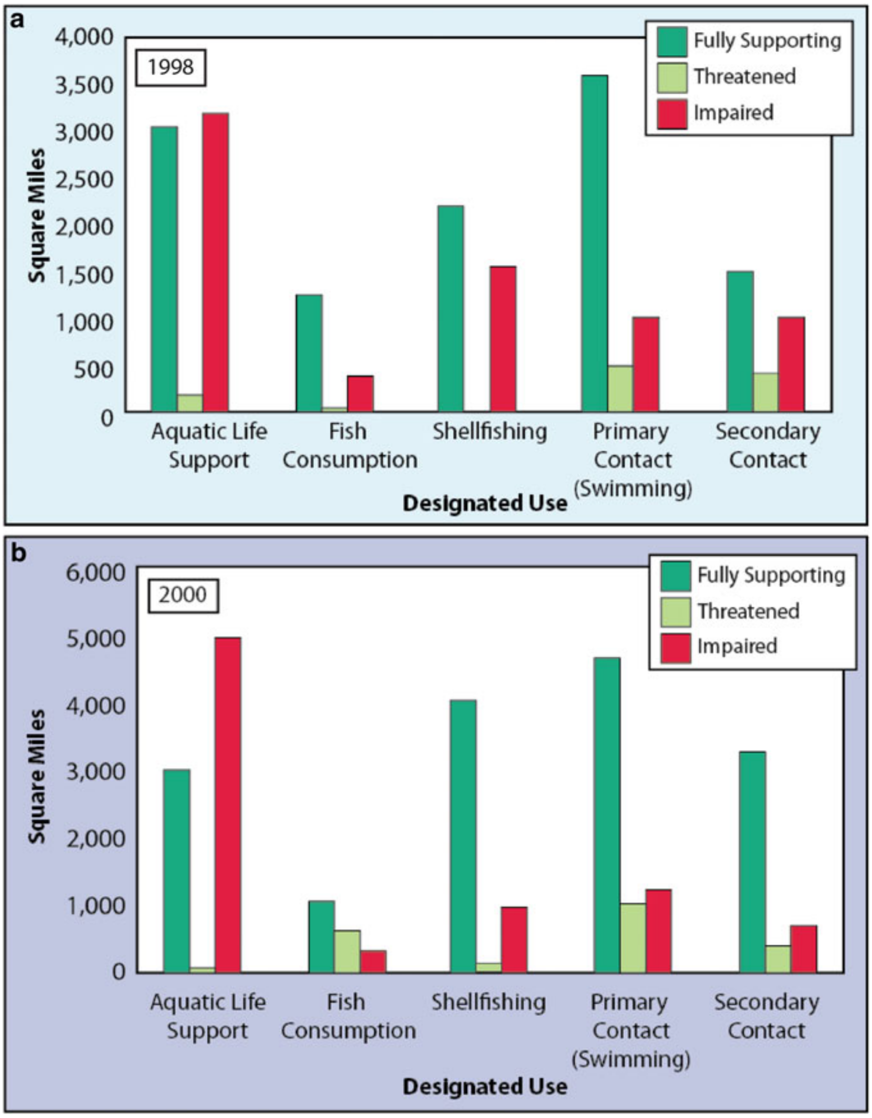

Figure 2.59. Individual use support for assessed estuaries in the Gulf Coast (a) 1998 (modified from USEPA 2001) and (b) 2000 (modified from USEPA 2004).

the assessed estuarine waters, 32 % fully supported their designated uses and 6 % were considered under threat for one or more uses (Figure 2.58a). Some form of contamination or habitat degradation impaired the remaining 62 % of the estuarine waters assessed. Individual use support for estuaries in 1998 and 2000 is shown in Figure 2.59. Of 16,195 coastal shoreline km (10,063 coastal shoreline mile), 296 km (184 mi) or 0.02 % were assessed in 2001. Of the shoreline miles assessed, 60 % fully supported the designated uses, 2 % were considered threatened for one or more uses, and 38 % were impaired by some form of contamination or habitat degradation (Figure 2.58b). In 2001, there were 233 waters in the Gulf of Mexico listed as impaired under Section 303(d) of the Clean Water Act. The percentage of listed waters impaired by major pollutant category is summarized in Figure 2.60. Of 41,069 km^2 (15,857 mi^2) of Gulf of Mexico estuaries 71 % (29,057 km^2 [11,219 mi^2]) were assessed for 2000 Clean Water Act 305(b) reports, which were generally based on data collected in the late 1990s (Figure 2.61).

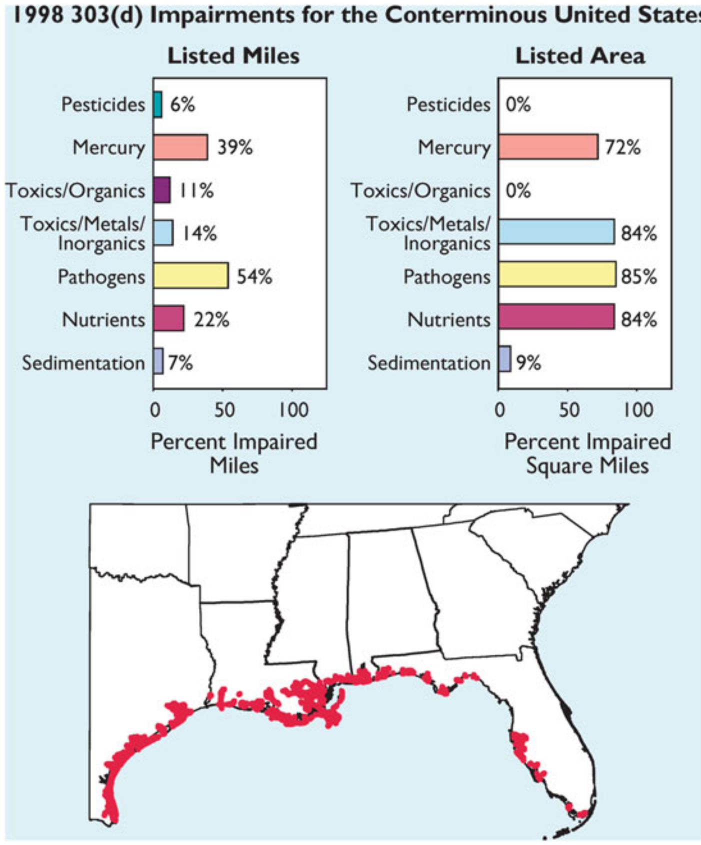

Figure 2.60. 1998 303(d) listed waters on the Gulf Coast and the percentage of listed waters impaired by the major pollutant categories. *Note*: 303(d) listing may be impaired by multiple pollutants (modified from USEPA 2001).

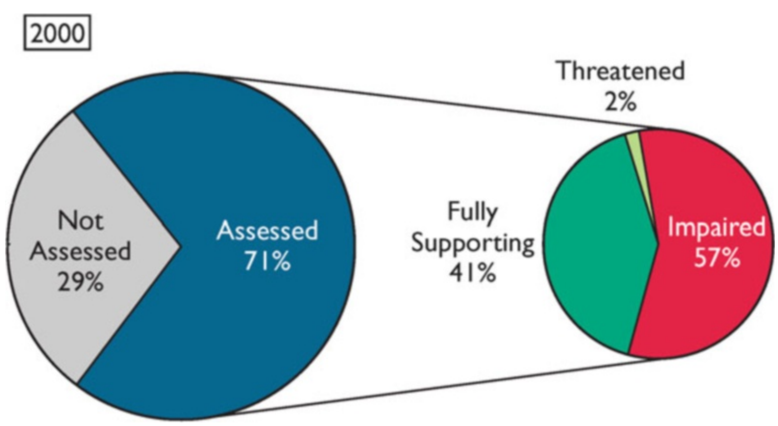

Figure 2.61. Water quality in assessed Gulf Coast estuaries in 2000 (modified from USEPA 2004).

As in 2001, it was not possible to distinguish between Atlantic and Gulf of Mexico listings; therefore, 305(b) assessment information for Florida was included in Gulf of Mexico summaries. Of the assessed estuarine waters along the northern Gulf of Mexico, 41 % fully support the designated uses and 2 % were considered threatened for one or more uses. Some form of pollution or habitat degradation impaired the remaining 57 % of assessed estuarine waters on the Gulf Coast.

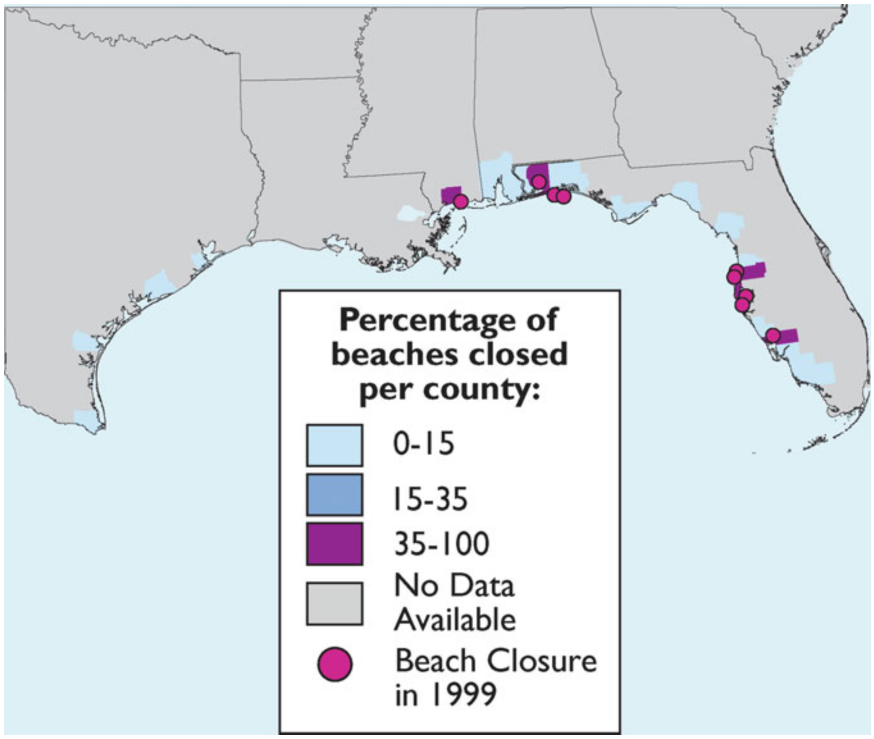

Figure 2.62. Locations of beaches for which information was available. Of the beaches submitting information, 13 % were closed at least once in 1999 (modified from USEPA 2001).

Information on monitoring and beach closures was reported to USEPA in 1999 by all Gulf States, except Louisiana (USEPA 2001). In total, 85 beaches reported with 85 % of respondents located in Florida. Of these 85 beaches, 79 % (67 beaches) had a water quality monitoring program. In Florida, 81 % of the beaches reported that monitoring was conducted in 1999 covering approximately 97 km (60 mi) of beach coastline. Ten beaches (14 % of those reporting) along Florida's coast reported closing at least once in 1999 (Figure 2.59). The primary reason for beach closures was elevated bacteria levels due to stormwater and other runoff. In Mississippi, only one coastal beach responded to USEPA's survey. The beach reported monitoring of 64 km (40 mi) of beach coastline that was partially closed twice in 1999. One beach in Louisiana on the south shore of Lake Pontchartrain was closed throughout 1998 due to elevated bacterial levels from sanitary sewer overflows and pipe breaks. In 2002, of the 176 coastal beaches in the Gulf of Mexico that reported information to USEPA, 37 % (65 beaches) were closed or under an advisory for some period of time. Florida's west coast had the most beaches with advisories or closures (Figure 2.62). Mississippi did not participate in the 2002 survey. Advisory and closure percentages for each county within each state are summarized in Figure 2.63.

Most advisories and closings at coastal beaches along the northern coastal Gulf of Mexico were due to elevated bacteria levels (Figures 2.64 and 2.66). Stormwater runoff, other unknown sources, and wildlife were frequently identified as sources of waterborne bacteria that resulted in advisories or closings. Unknown sources accounted for 36 % of the responses (Figure 2.65). In Florida, 39 % (52 of 134) of beaches reported an advisory or closing at least once during 2002. The primary reasons for public beach notifications were preemptive actions due to rainfall events or the detection of elevated bacteria levels from unknown sources, stormwater and other runoff, wildlife, boat discharges, septic systems, and publically owned treatment works

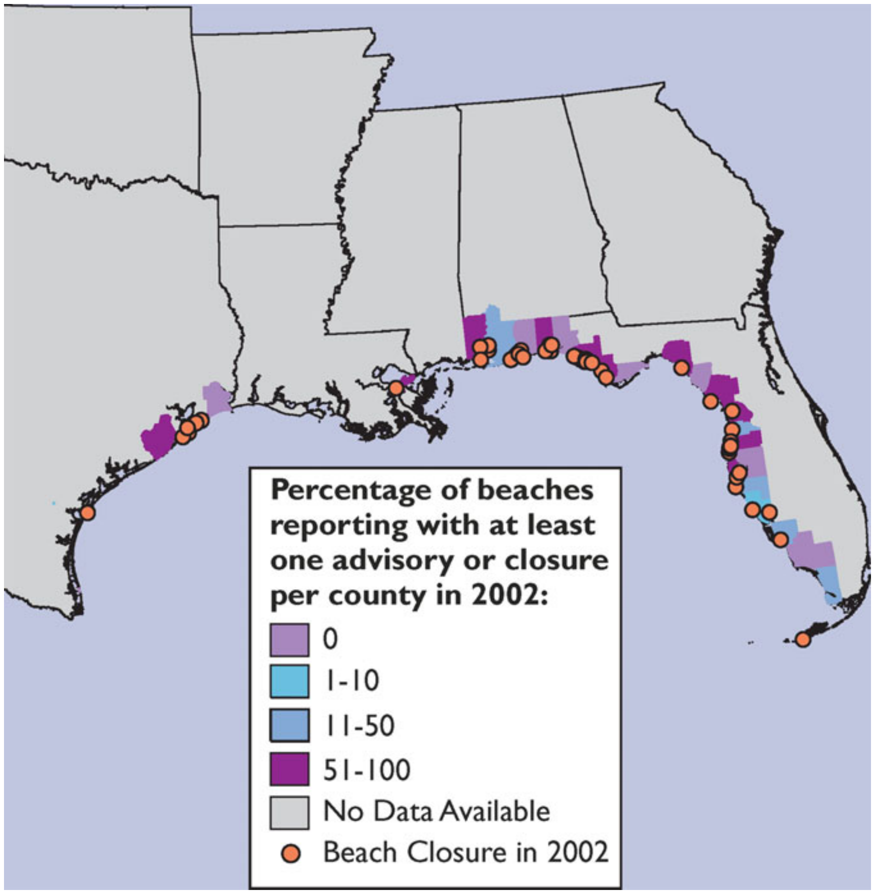

Figure 2.63. Percentage of Gulf Coast beaches with advisories or closures by county in 2003 (modified from USEPA 2004).

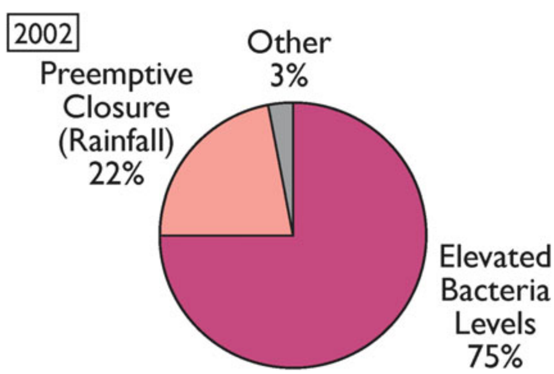

Figure 2.64. Reasons for beach advisories or closures on the Gulf Coast (modified from USEPA 2004).

(POTW) discharges. In Alabama, 4 of 11 responding beaches (36 %) reported advisories or closures during 2002 from elevated bacterial levels due to stormwater runoff, unknown sources, wildlife, and sewer line blockage or pipe breakage. In Louisiana, one beach on the south shore of Lake Pontchartrain reported being affected by a year-long advisory or closure during 2002 due to elevated bacterial levels from POTWs, sewer line blockage or pipe breakage,

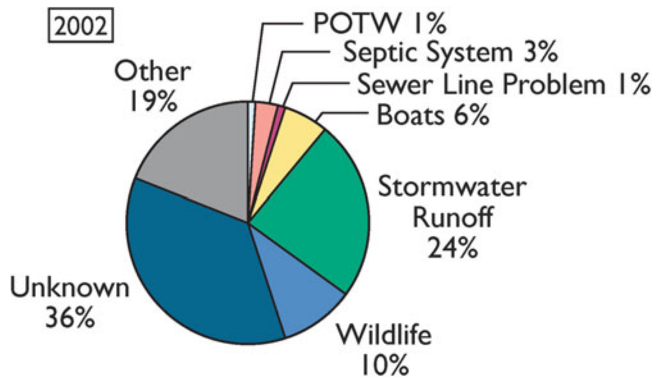

Figure 2.65. Sources of beach contamination on the Gulf Coast (modified from USEPA 2004).

and stormwater runoff. In Texas, 8 of 30 responding beaches reported advisories or closures during 2002 due to elevated bacteria levels from unknown sources, stormwater runoff, wildlife, septic systems, boat discharges, sanitary sewer overflows, and sewer line blockage or pipe breakage. Of the 619 coastal beaches in the northern Gulf of Mexico that reported to USEPA, 23 % (144 beaches) were closed or under an advisory in 2003. Florida's west coast had the most beaches with advisories or closures. Louisiana did not respond to the survey (USEPA 2006) (Figure 2.66).

Water quality can also be reflected in the number and type of fish consumption advisories. However, as indicated, a comprehensive review of seafood advisories in the northern Gulf of Mexico is beyond the scope of this review. Contaminants in fish and other seafood can be caused by a variety of sources other than direct uptake from water, but the levels of contaminants in fish tissues provide an indication of potential degraded water quality due to contaminants. A 3-year snapshot is provided as an example to illustrate the extent of the problems causing most concern in the northern Gulf of Mexico. In 2000, 2001, and 2003, there were 14, 13, and 14 fish consumption advisories in effect for the estuarine and marine waters of the Gulf of Mexico, respectively (Figure 2.67) (USEPA 2001, 2004, 2008). Most advisories (10, 12, and 2 in 2000, 2001, and 2003, respectively) were issued for mercury, and all Gulf States had one statewide coastal advisory in effect for mercury in king mackerel all 3 years. As a result of the statewide advisories, 100 % of the coastal miles of the northern Gulf of Mexico were under advisory for all 3 years and 64, 27, and 27 % of the estuarine square miles were under advisory in 2000, 2001, and 2003, respectively. Advisories placed on specific water bodies included additional pollutants and fish species. For example, in 2000, Bayou d'Inde in Louisiana was under an advisory for all fish and shellfish due to contamination by PCBs, mercury, hexachlorobenzene, and hexachlorobutadiene. Florida had four additional mercury advisories, in addition to the statewide coastal advisory. In Texas, the Houston Ship Channel was under advisory for catfish and blue crabs due to contamination by dioxins/furans (2000 and 2001). Most advisories (12) were issued for mercury, and each Gulf State had a statewide coastal advisory in effect for mercury in king mackerel. As a result of the statewide advisories, 100 % of the coastal miles in the Gulf of Mexico and 23 % of the estuarine square miles were under advisory in 2002 (Figure 2.67). In 2001, Florida had eight mercury advisories in effect for a variety of fish in addition to the statewide coastal advisory. In 2003, the Houston Ship Channel was under advisory for all fish species because of contamination by chlorinated pesticides and PCBs. Potential dioxin contamination in catfish and blue crabs resulted in additional advisories for the Houston Ship Channel.

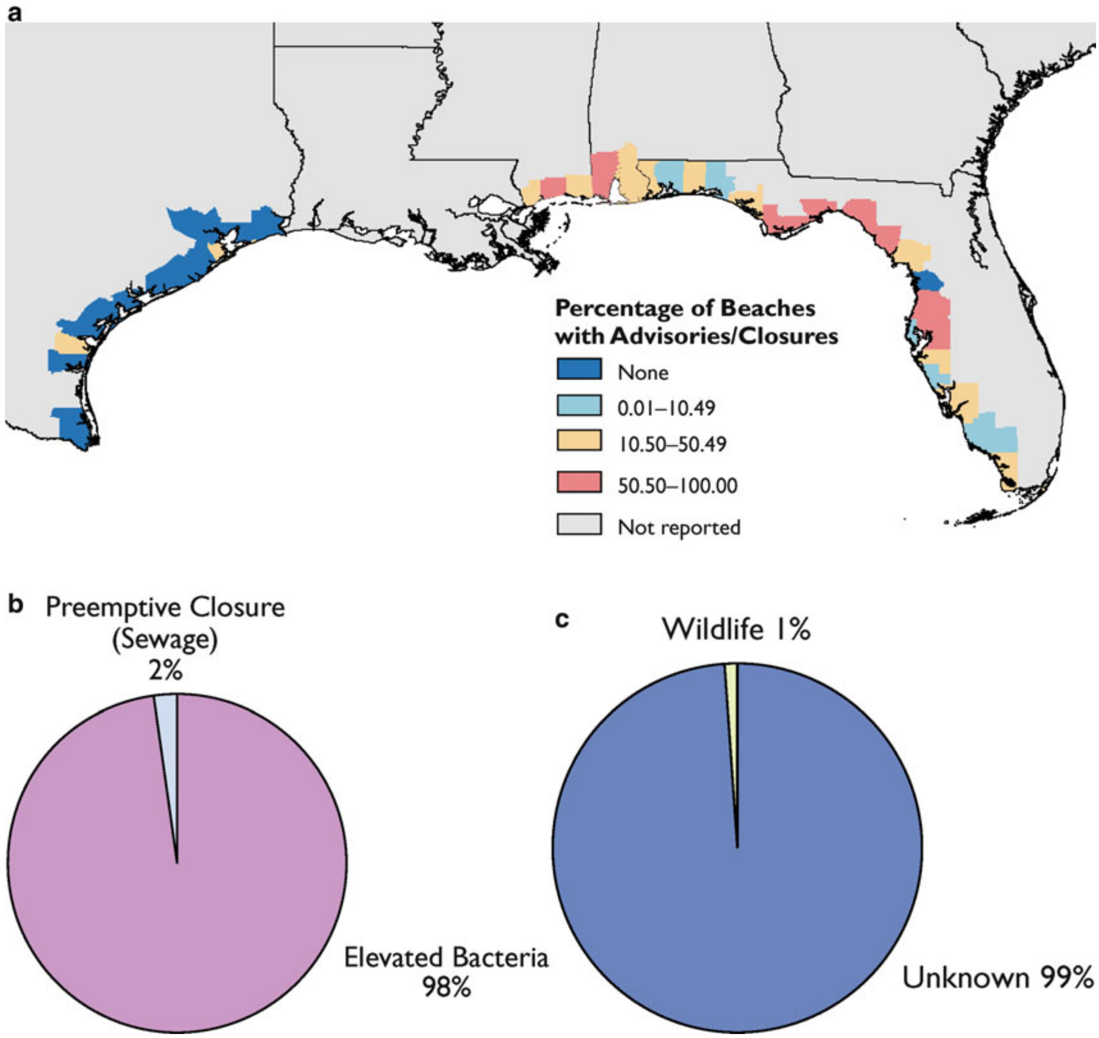

Figure 2.66. (a) Percentage of monitored beaches with advisories or closures by county for the Gulf Coast region; (b) reasons for beach advisories or closures for the Gulf Coast region; and (c) sources of beach contamination resulting in beach advisories or closures for the Gulf Coast region (modified from USEPA 2008).

Integrated assessments, beach closings, seafood consumption advisories, and contaminant levels in selected species show that degraded environmental conditions have impaired many northern Gulf of Mexico estuaries, shorelines, and beaches in regard to the services they provide to ecosystems and humans. Coastal environments are exposed to a wide range of influences that can degrade environmental quality. It is the cumulative effect of these factors that leads to impairment, making it difficult to ascribe degradation to a single causative factor such as water quality. However, degraded water due to chemical and biological contaminants is implicated as at least a contributor to degraded environments at numerous locations across the northern Gulf of Mexico. Human health has been demonstrated to be at risk due to consumption of seafood and exposure to contaminated waters that are contaminated by chemicals and pathogens. Upwards of 60 % of assessed estuaries were impaired for use by ecosystems and/or humans while many others were considered threatened. Locations of impairment are often closely associated with high concentrations of human populations (urban areas) along the coast that are also associated with human activities that introduce excess nutrients and contaminants

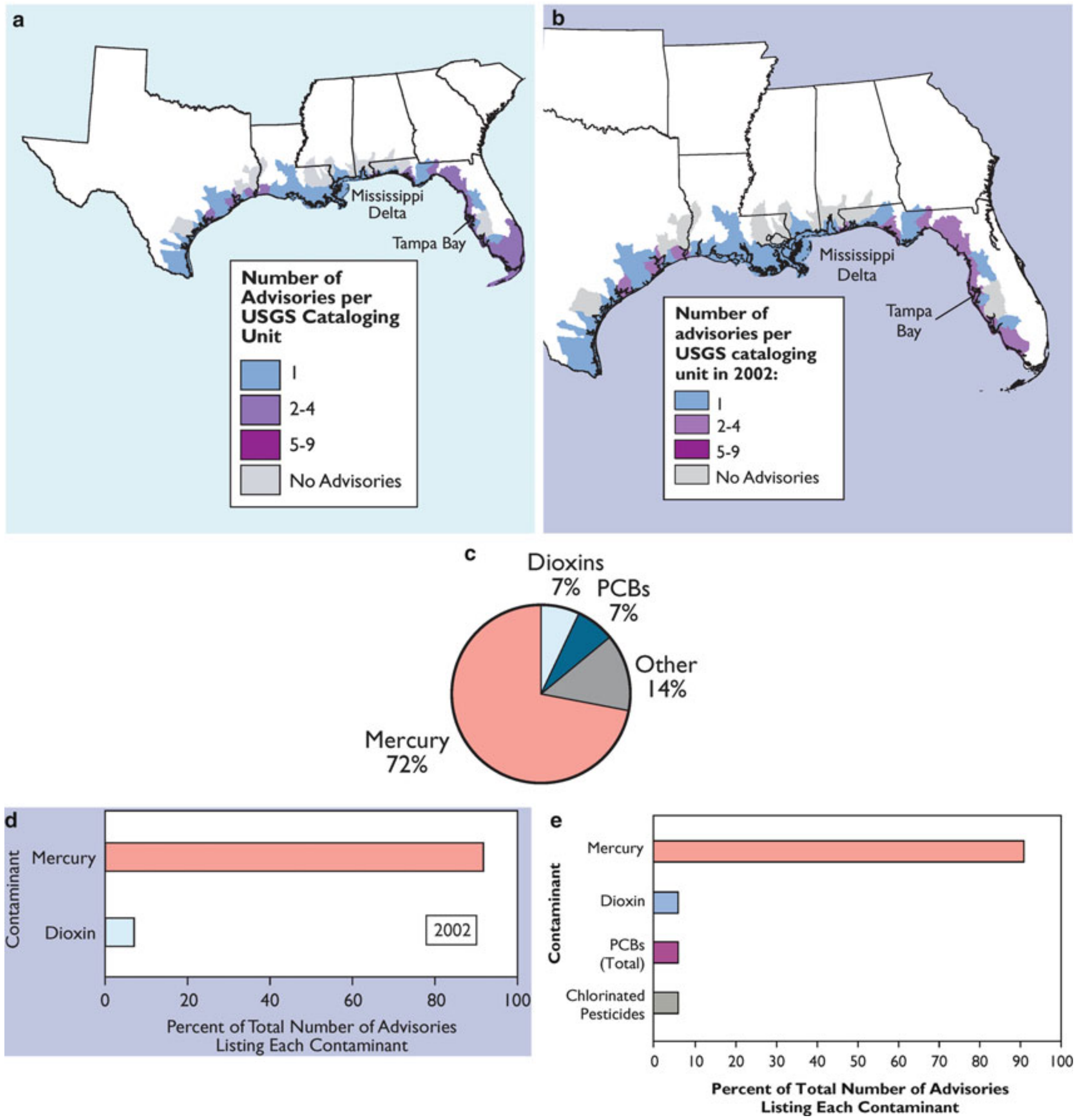

Figure 2.67. (a) Number of fish advisories active in 2000; (b) number of fish advisories active in 2002; (c) percentage of estuarine and coastal marine advisories issued for each contaminant on the Gulf Coast; (d) percentage of estuarine and coastal marine advisories issued for mercury and dioxin on the Gulf Coast in 2002; and (e) percentage of estuarine and coastal marine advisories issued for each contaminant on the Gulf Coast (modified from USEPA 2001, 2004, 2008).

to coastal environments. The reasons for impairment are highly variable and location dependent, and locations can be impaired due to more than one factor. The inflows of large river systems are also associated with impairment. Contaminant-related impairment at individual locations has been attributed to the presence of pesticides, mercury, other organic contaminants and pathogens. In the early 2000s, many advisories were issued due to the presence of mercury in certain species of fish; mercury is by far the most ubiquitous metal chemical contaminant detected in fish tissues along the northern Gulf of Mexico coast. At specific locations in highly urbanized and industrial estuaries, the concentrations of PCBs, chlorinated pesticides, and dioxins/furans in fish tissues resulted in the issuance of consumption advisories. However, it is unclear if these occurrences are caused by degraded water quality since chemical contaminants accumulate in biological tissues via other pathways (e.g., ingestion of contaminated sediments and dietary foods). For beach closing, this is almost exclusively associated with waterborne pathogens discharged into coastal waters from a variety of sources suggesting that water quality itself may be degraded. As indicated previously, a comprehensive review of beach closings, consumption advisories, and biological tissue contaminant concentrations is beyond the scope of this review, but the examples provided give insight into which chemical and biological contaminants in addition to petroleum are of environmental concern across the northern Gulf of Mexico. No comprehensive mass loading summaries are available for other organic and inorganic contaminants that are of environmental concern. However, extensive quantitative surveys of contaminated sediments and sentinel organism (oyster and mussels) contaminant burdens are available and reviewed elsewhere.

2.3.9 Temporal Trends in Coastal Water Quality

A question when considering water quality and its causes is whether conditions are getting better, getting worse, or staying the same. Since water quality in the coastal waters of the northern Gulf of Mexico has been assessed since 1991 these data can be used to detect trends over time (USEPA 2001, 2004, 2008). Only two water quality indicators were comparable in these two time frames: dissolved oxygen concentrations and water clarity. Year-by-year data showed no significant trend with time in the percent of area rated poor (Figure 2.68) (USEPA 2008). When the two time periods were compared, significantly more of the coastal area was rated poor for water clarity in the 2000–2002 time period than in the 1991–1994 time period. Longer-term temporal trends can be masked by interannual variations due to weather and climate that cause large short-term variations in water quality.

A second opportunity to assess long-term temporal changes was availed by NOAA's updating of the 1999 report on eutrophication in 2007 (Bricker et al. 1999, 2007). The updated assessment in 2007 identified eutrophication status and change since the 1999 report, tracked management progress, and identified potential solutions to eutrophication problems. These assessments gave insight into water quality trends over a 10-year period. Trends in eutrophication were assessed by examining influencing factors, eutrophic symptoms, overall eutrophic condition and future outlooks. The results were combined into an overall rating. As described previously, factors that influence eutrophication include nitrogen loading and the estuary's susceptibility to excess nutrients based on dilution and flushing rates. Overall eutrophic condition was based on an assessment of five indicators: chlorophyll *a* concentrations, macroalgae biomass, dissolved oxygen concentrations, submerged aquatic vegetation gain/loss, and nuisance/toxic blooms. Eutrophic condition was determined by evaluating the occurrence, spatial coverage, and frequency of these symptoms. In the 1999 report, the future outlook for eutrophic condition in the year 2020 was predicted based on expected changes in nutrient loads and an estuary's susceptibility to these loadings (Figure 2.69). The completeness and reliability of the assessment was a function of the availability and quality of data.

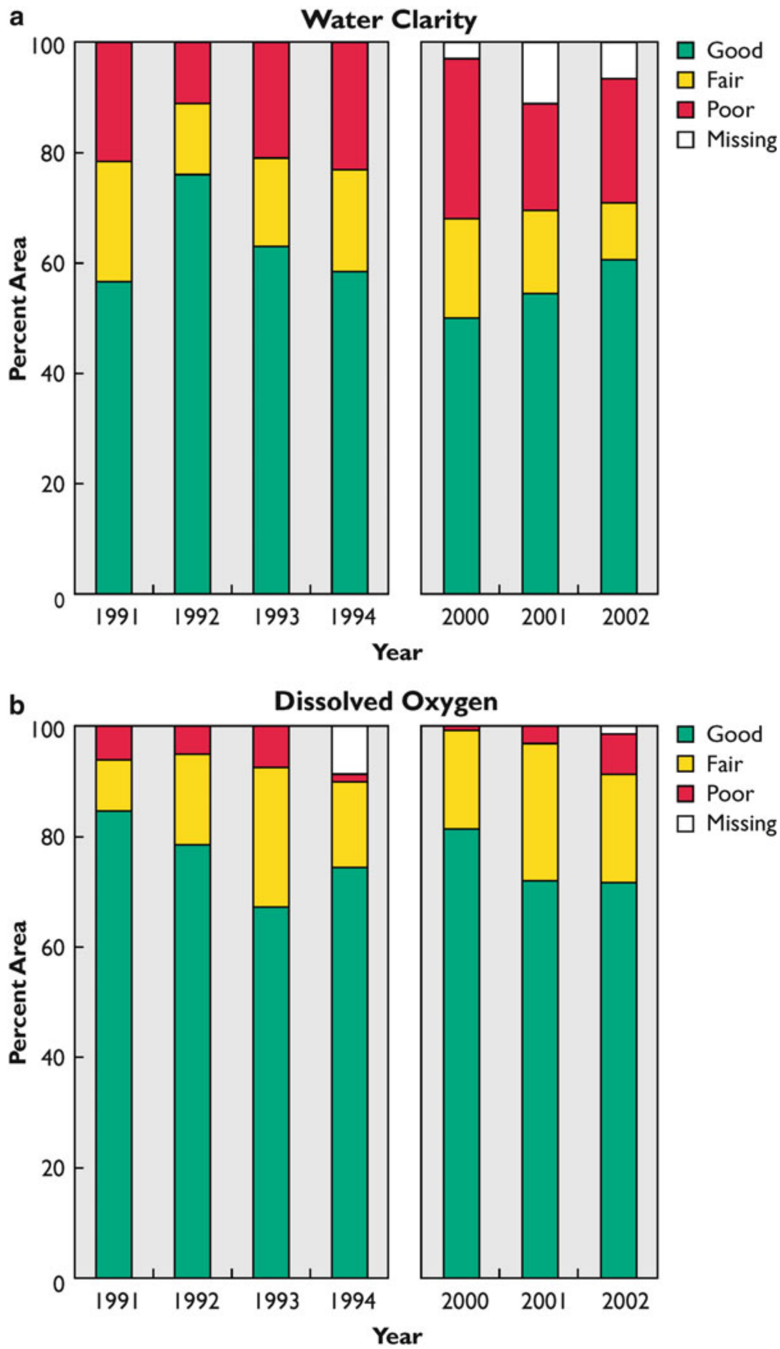

Figure 2.68. Percent of area of northern Gulf of Mexico waters rated as good, fair, poor, or missing for (a) water clarity and (b) dissolved oxygen concentrations measured over two time periods, 1991–1994 and 2000–2002 (modified from USEPA 2008).

The 1999 assessment concluded that Gulf of Mexico estuaries were mostly large, shallow, and poorly flushed leading to predictions of worsening eutrophication conditions. The estuaries tended to have large watersheds by area that support low to moderate human populations. Factors influencing eutrophication were high for a majority of assessed estuaries (Figure 2.70). A small proportion of estuaries had high or moderately high overall eutrophic condition in 2007

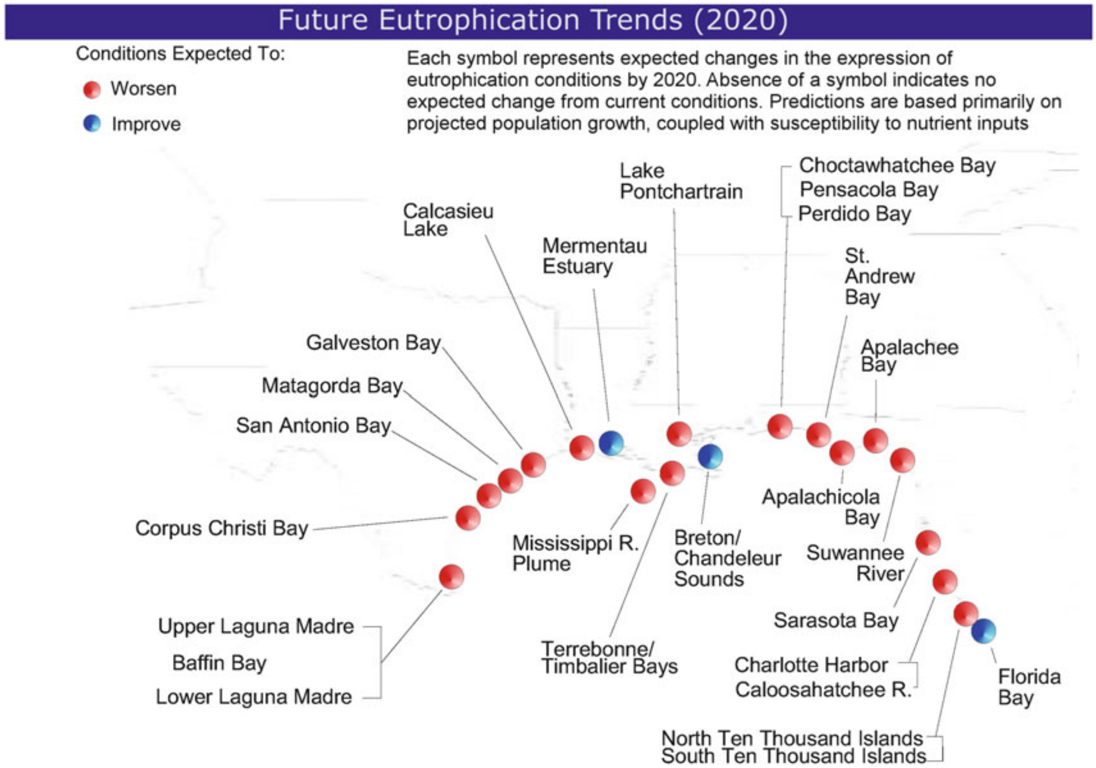

Figure 2.69. Expected trends in eutrophication through 2020 predicted in 1999 (modified from Bricker et al. 1999).

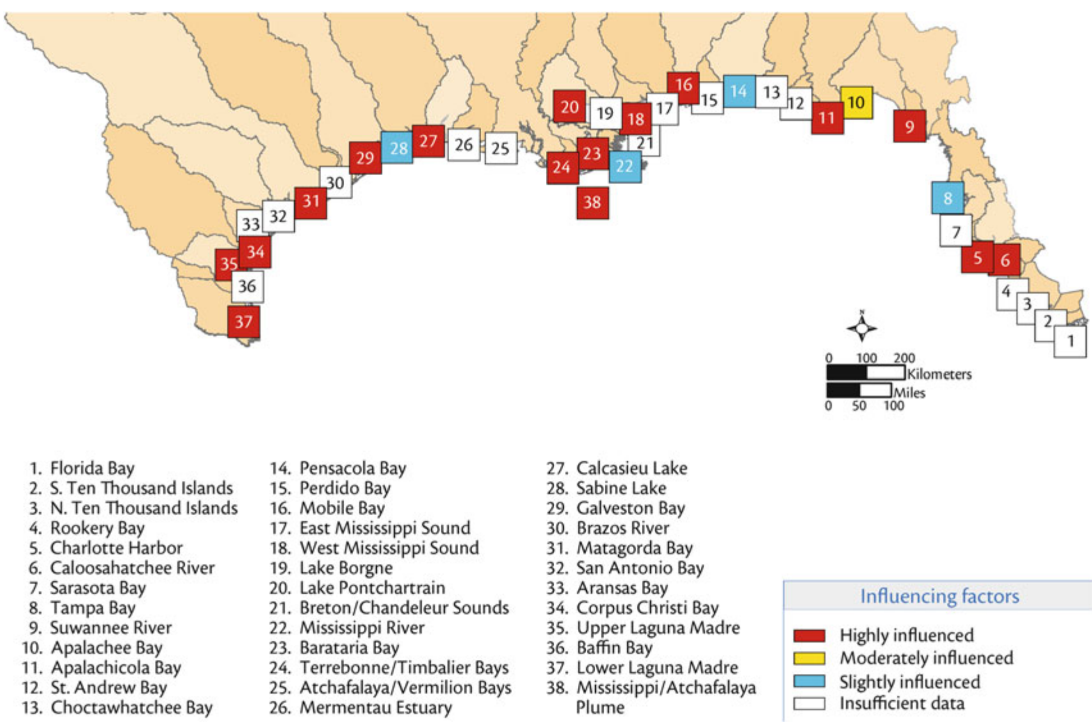

Figure 2.70. Map of influencing factor ratings for Gulf of Mexico estuaries in 2007 (modified from Bricker et al. 2007).

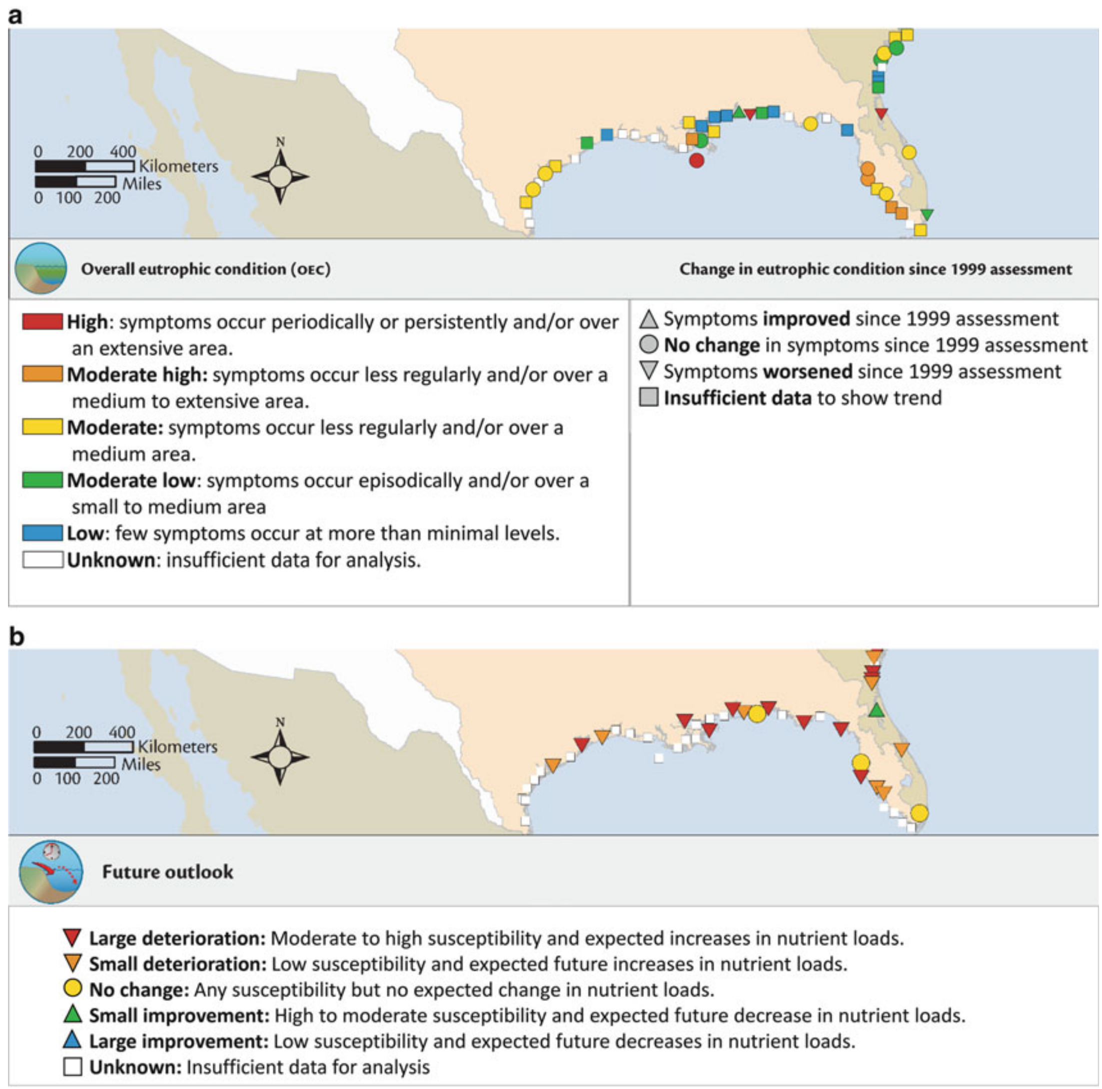

Figure 2.71. (a) Overall eutrophication condition and (b) future outlook for eutrophication conditions for the Gulf of Mexico estuaries (modified from Bricker et al. 2007).

(Figure 2.71). Gulf of Mexico estuaries were characterized as having high and often worsening chlorophyll *a* symptoms. Watershed nitrogen inputs were determined to be high in over 80 % of the estuarine systems assessed in the northern Gulf of Mexico. However, nitrogen loading data was limited, with no information available for about half of the estuaries. Nitrogen loadings were considered low for only two of the 38 estuaries—Tampa Bay and Pensacola Bay. Not unexpectedly, the Mississippi River had the largest nutrient load of all U.S. rivers at the time. Nutrient load estimates for the Mississippi River were used to calculate influencing factor ratings for both the Mississippi River and Mississippi/Atchafalaya Plume. Most estuaries in the northern Gulf of Mexico have shallow water depths and small tidal ranges that suggest low dilution and flushing rates. As a consequence, most estuaries were judged to have a moderate to high susceptibility to nutrient loading (Figures 2.70 and 2.71). The combination of effects of high nitrogen loads and moderate or high susceptibility to nutrients results in most estuaries being assigned high influencing factor ratings (except for Tampa Bay and Pensacola Bay) (Figure 2.70).

For estuaries where data were available, most eutrophication symptoms showed low to moderate expressions (Figure 2.71). The exception was chlorophyll *a* concentrations where 17 estuaries exhibited high level and five exhibited moderate level conditions. The systems with high chlorophyll *a* expression were mostly located in Florida and Texas (Figure 2.72a). The other primary symptom, macroalgae abundance, was high in only three estuaries and moderate in four; however, 24 estuaries had insufficient data for assessment (Figure 2.72b). Of the secondary symptoms, significant dissolved oxygen problems were reported in only two estuaries (Perdido Bay and the Mississippi Plume, Figure 2.72c). Five estuaries had moderate nuisance/toxic bloom expressions and 11 were rated as low (Figure 2.72d). All 11 assessed estuaries exhibited low-level loss of submerged aquatic vegetation (Figure 2.72e).

Based on comparisons of the 1999 and 2007 assessments, conditions were worse in one estuary and improved in another. Worsening conditions in Perdido Bay were caused by decreases in dissolved oxygen concentrations (Figure 2.73). In Mobile Bay, improved dissolved oxygen concentrations and fewer nuisance/toxic blooms were noted. For 16 estuaries, assessments were made in 1999 and 2004 but the indicators used were not comparable between assessments. Of the 38 Gulf of Mexico estuaries studied, 13 were predicted to develop worsening conditions, eight to a high degree and five to a lesser degree (Figure 2.73). For Tampa Bay, which had experienced regrowth and gains in the spatial coverage of submerged aquatic vegetation, the conditions were expected to remain the same due to management strategies to compensate for expected increases in nutrient loads from population growth. For Charlotte Harbor, the prediction of worsening conditions was due to land use changes from low to high intensity usage (e.g., rangeland to row crops or urban). Other factors potentially influencing future changes were urban runoff, wastewater treatment, industry, atmospheric deposition, animal operations (Sabine Lake), and agriculture activities (crops and rangeland or pasture). There were no estuaries for which conditions were expected to improve. Future conditions for 23 estuaries were unknown, making it difficult to draw overall conclusions about the region; however, many of the estuaries were expected to experience worsening eutrophication. In 2007, the future outlook was the same as it was in the early 1990s with worsening conditions predicted in all estuaries for which data were available. For 10 estuaries where evaluations were possible, 1999 predictions for 2020 were already realized in 2007, only 8 years later.

Galveston Bay water quality was monitored for a number of years at a finer spatial scale than the assessments described above to detect trends with time (USEPA 2006) (Figure 2.74). Indicators for monitoring water quality conditions in the estuary included dissolved oxygen, nitrogen (e.g., nitrate, nitrite, ammonia), total phosphorus, and chlorophyll *a* concentrations; TSS/turbidity; salinity; water temperature; pH; pathogens (e.g., Enterococci, fecal coliform); biochemical oxygen demand (BOD); and total organic carbon (TOC). Declines in annual average ammonia levels were observed in several areas of Galveston Bay with the most dramatic decline in the Houston Ship Channel. For the most part, annual average concentrations were below screening levels. Nitrate-nitrite concentrations were highest in the Houston Ship Channel which demonstrated an increasing trend from about 0 mg/L in 1969 to 1.75 mg/L in 2001. The Intracoastal Waterway East exhibited a significant decline in nitrate-nitrite, and the Trinity River had a significant decline in phosphorus (since 1969). None of the five sub-bays of Galveston Bay showed trends exceeding the estuarine screening levels for nutrients (Lester and Gonzalez 2003). Annual average concentrations of chlorophyll *a* had declined across all Galveston Bay sub-bays and tributaries since 1969, with the largest decreasing trend in chlorophyll *a* concentrations found in the Houston Ship Channel, San Jacinto River, and

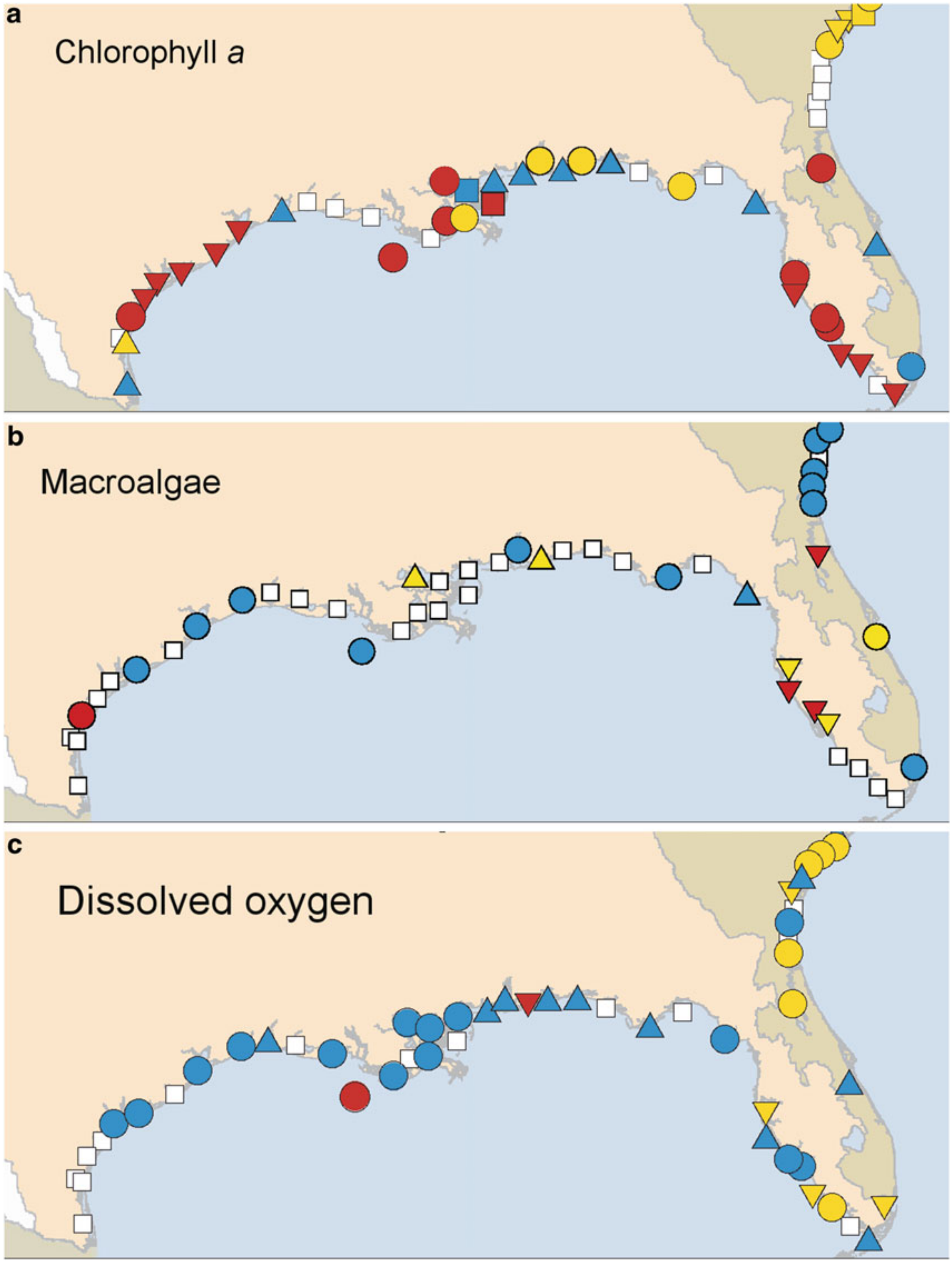

Figure 2.72. Expression of eutrophication symptoms: (a) chlorophyll *a*, (b) macroalgae, (c) dissolved oxygen, (d) nuisance/toxic algal blooms, and (e) submerged aquatic vegetation for Gulf of Mexico estuaries in 2007 (modified from Bricker et al. 2007).

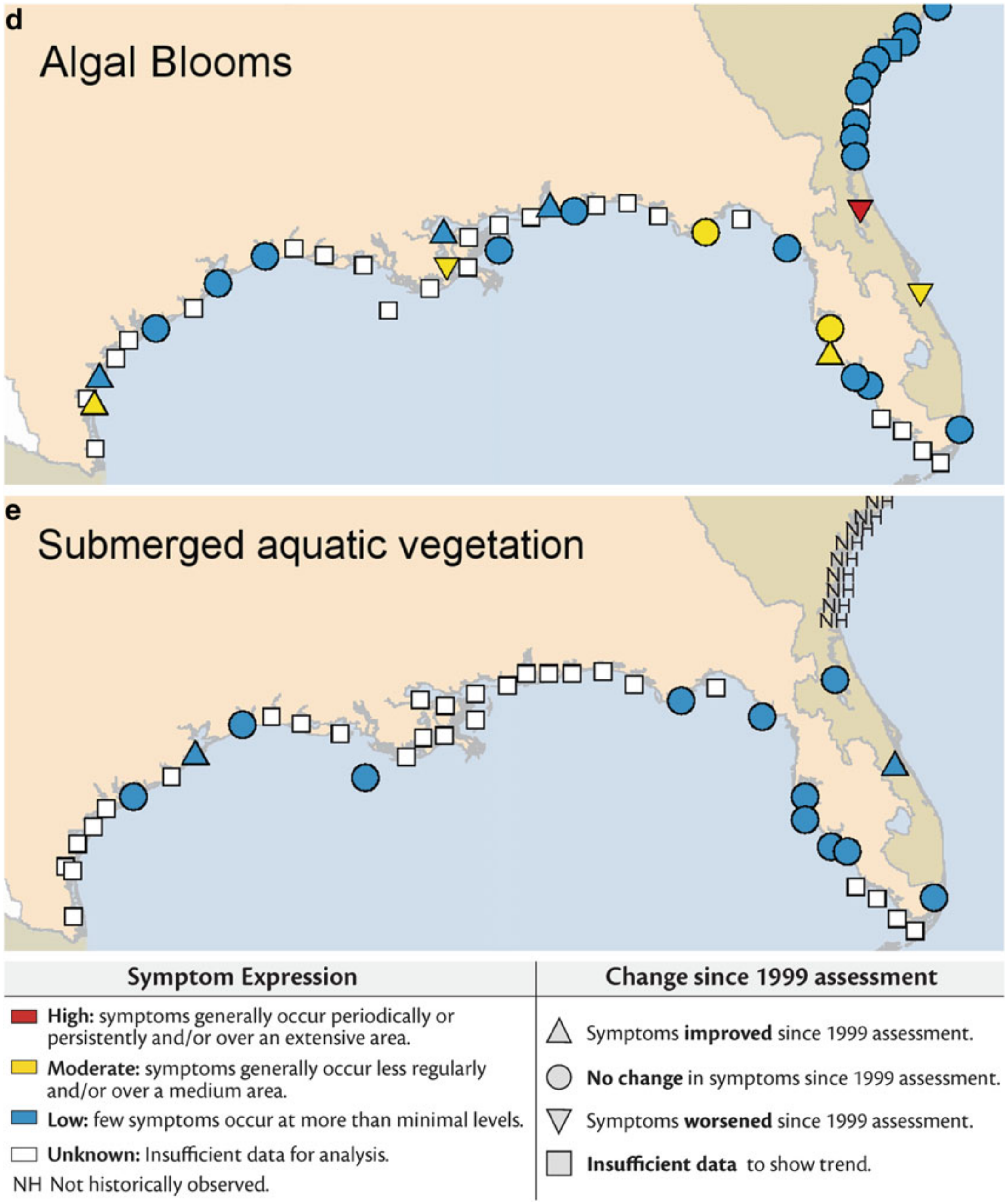

Figure 2.72. (continued)

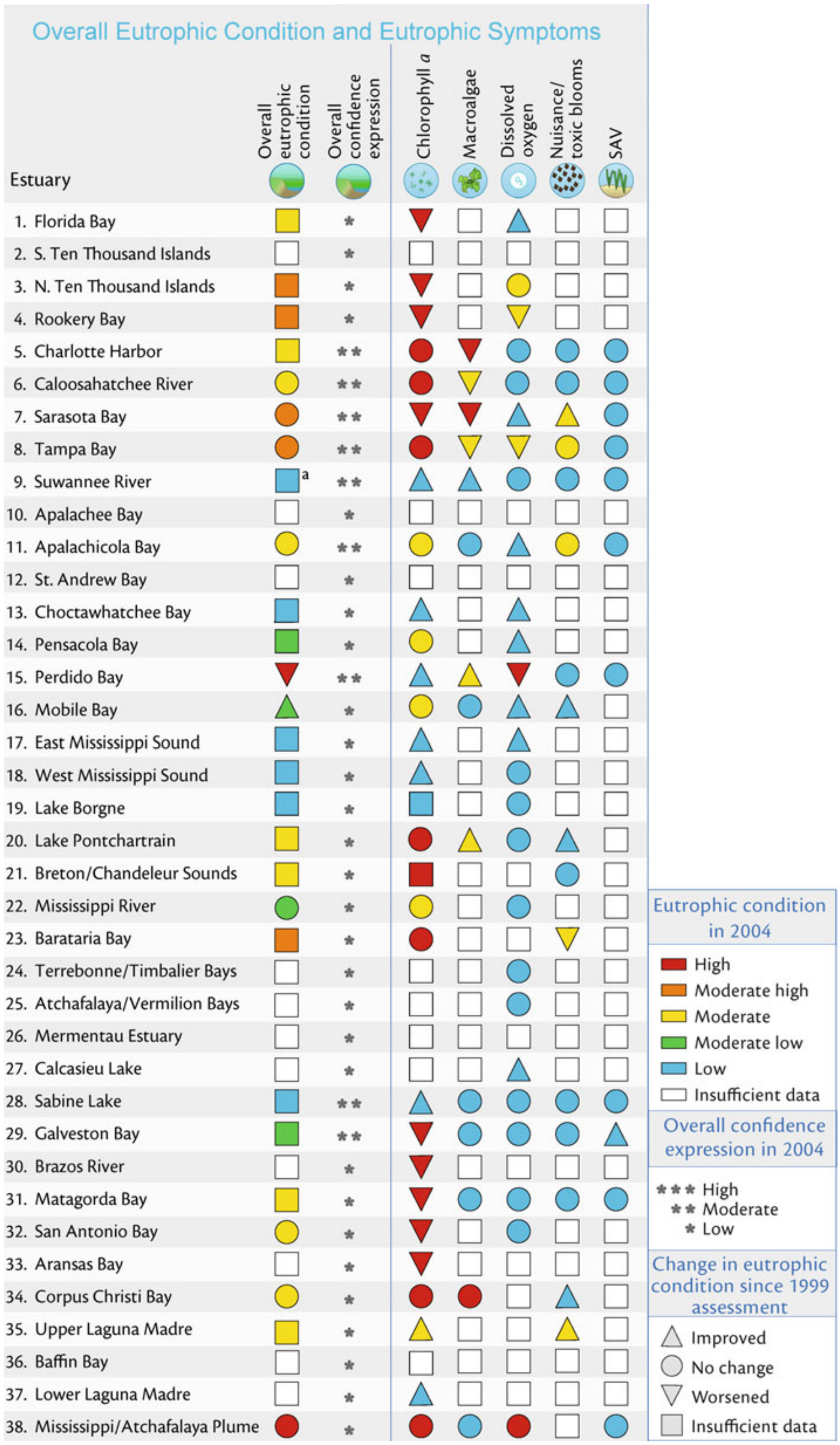

Figure 2.73. Gulf of Mexico future outlook in 2004 and compared to the 1999 future outlook (modified from Bricker et al. 2007; *SAV* submerged aquatic vegetation).

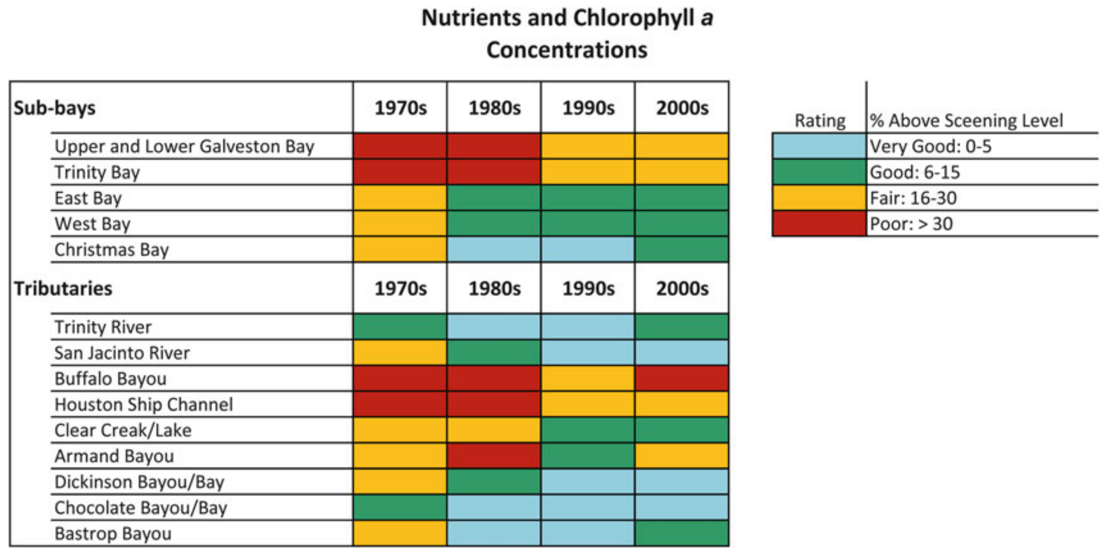

Figure 2.74. Texas Commission for Environmental Quality (TCEQ) water quality ratings for Galveston Bay nutrients and chlorophyll *a* concentrations (modified from Lester and Gonzalez 2005).

Texas City Ship Channel. Monthly average concentrations of chlorophyll *a* did not show a trend in any of the five sub-bays in Galveston Bay. Survey data collected in 2000 and 2001 for the West Bay region averages were similar to previous Texas Commission for Environmental Quality (TCEQ) data, but chlorophyll *a* concentrations were slightly higher (Lester and Gonzalez 2003). Sub-bays were rated as moderate to good for the period 1990–2003, as compared to poor ratings for 2000–2001, though rating criteria varied among studies (Lester and Gonzalez 2005). Nutrients in Galveston Bay proper remained fairly constant during the year; however, nutrient concentrations in Galveston Bay tributaries were highest in the summer months. Overall, water quality was seen as improving in Galveston Bay since the 1970s (Lester and Gonzalez 2005). TSS showed declines in annual average concentrations across all sub-bays and tributaries of the Galveston Bay system, with the exception of Upper Galveston Bay, Lower Galveston Bay, and Cedar Bayou (Lester and Gonzalez 2003). Galveston Bay is naturally turbid because of its shallow depth and fine sediments. However, dredging activities, commercial fisheries, and natural and man-made erosion enhance natural turbidity.

Pathogens monitored in Galveston Bay included Enterococci, *E. coli*, and fecal coliform. According to the 2005 Galveston Bay Indicators Project, the areas of Galveston Bay with the greatest number of TCEQ criteria-level exceedances for fecal coliform bacteria were Buffalo Bayou, the Houston Ship Channel, Clear Creek, and Dickinson Bayou (Figure 2.75). A decline in fecal coliform was found in the East Intracoastal Waterway area but the other four major subareas of the bay did not show a trend in fecal coliform counts. The areas with the highest concentrations of Enterococci were the Houston Ship Channel, East Intracoastal Waterway, San Jacinto River, and Trinity Bay, whereas areas with the lowest concentrations were Galveston Channel, Texas City Channel, Christmas Bay, Bastrop Bayou Complex, Dickinson Bayou/Dickinson Bay, and East Bay (Lester and Gonzalez 2003). In Galveston Bay, sediments, metals, and organic contaminants appeared to follow the same general spatial distribution, as do most other water quality parameters. Elevated concentrations of contaminants occurred in regions of runoff, freshwater inflow, and waste discharges, and lower, relatively uniform concentrations occur in the open bay. The upper Houston Ship Channel was generally the location of maximum concentrations of contaminants (Lester and Gonzalez 2005).

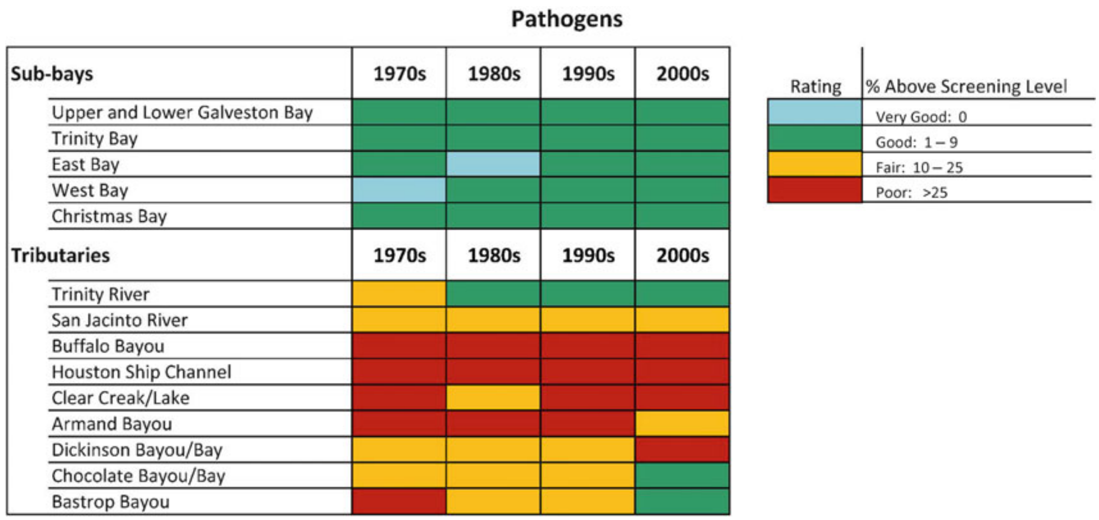

Figure 2.75. Texas Commission for Environmental Quality (TCEQ) water quality ratings for Galveston Bay pathogens (modified from Lester and Gonzalez 2005).

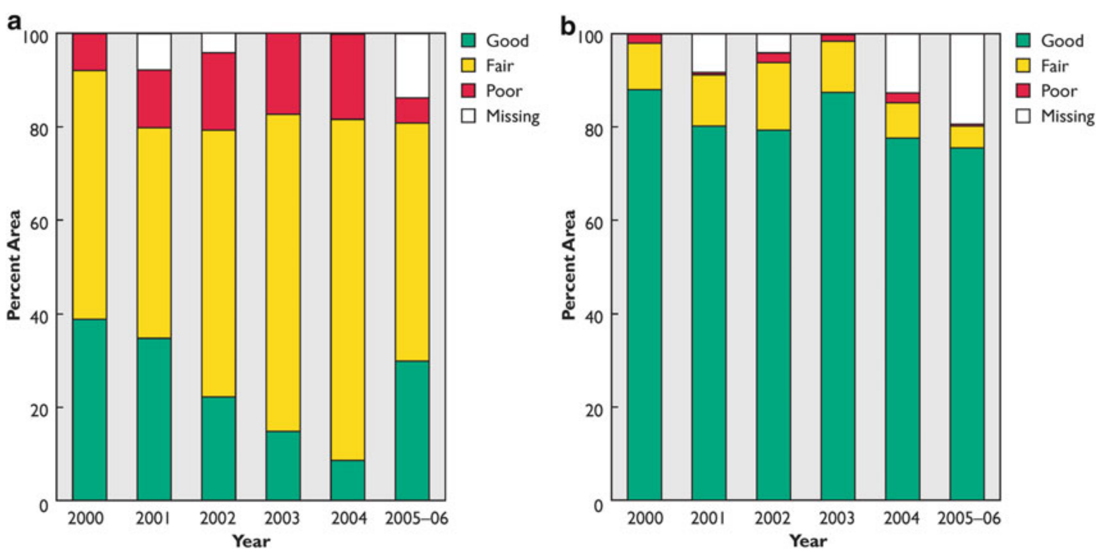

Figure 2.76. Percent area of Gulf Coast coastal waters in good, fair, poor, or missing categories for (a) water quality index and (b) DIN measured from 2000 to 2006 (modified form USEPA 2012).

Finally, 7 years of monitoring data (2000–2006) from Gulf Coast coastal waters was used to investigate temporal changes in water quality (National Coastal Conditions Reports II, III, and IV) (USEPA 2004, 2008, 2012). Interannual variation was evaluated by comparing annual estimates of percent area in poor condition for each indicator, and the associated standard error and trends in the percent area in poor condition for each indicator were evaluated using the Mann-Kendall test (USEPA 2012). The water quality index and its component indicators showed no significant linear trend over time in the percent area rated in poor condition (Figure 2.76).

2.4 CONTINENTAL SHELF/SLOPE AND ABYSSAL WATER QUALITY

In contrast to the record of monitoring programs in coastal environments, data concerning water quality on the continental shelf/slope and the abyssal deep of the northern Gulf of Mexico are sparse with a few notable exceptions. This is primarily due to the majority of offshore areas being remote from most human activities known to affect water quality. While these influences are often concentrated in coastal areas and rapidly lessen in intensity with distance offshore, human activities and natural processes have the potential to degrade continental shelf/slope and abyssal water quality. For many years the northwestern/central continental shelf of the Gulf of Mexico has been experiencing intermittent hypoxic events, commonly known as *dead zones*, associated with nutrient enrichment delivered to the Gulf of Mexico by the Mississippi River system. Atmospheric deposition of pollutants from the coast can extend into offshore regions. The most widespread anthropogenic activity in the offshore regions of the Gulf of Mexico is the exploration for, and the extraction of, oil and gas. A large percentage of oil and gas platforms in the Gulf of Mexico are located in the offshore regions (Figure 2.45). Transportation activities in the offshore area include commercial ship traffic both transiting and supplying platforms, a maze of petroleum pipelines to offshore facilities, commercial fishing fleets, and recreational boating. The offshore regions of the Gulf of Mexico are also the locations of most of the natural oil and gas seepage in the northern Gulf of Mexico.

2.4.1 Hypoxia on the Continental Shelf

In the Gulf of Mexico, coastal water hypoxia due to eutrophication is generally a localized occurrence within bays with vulnerable environmental settings (i.e., areas with low flushing rates and large inflows). However, along the northwest/central Gulf of Mexico continental shelf, the seasonal occurrence of waters with low concentrations of oxygen is now known to be geographically widespread (Figure 2.77). The northern Gulf of Mexico hypoxic zone is the second largest area of oxygen-depleted waters in the world (Rabalais et al. 2002). From 1985 to 1992, the areal extent of bottom-water hypoxia in the zone during midsummer averaged 7,770 km^2 (3,000 mi^2), and the average area doubled to 16,835 km^2 (6,500 mi^2) between 1993 and 1997 (Rabalais et al. 1999). In the summer of 2000, the area of the Gulf of Mexico hypoxic zone was reduced to 4,403 km^2 (1,700 mi^2) following a severe drought in the Mississippi River watershed. In 2002, the hypoxic zone had increased in size to 22,015 km^2 (8,500 mi^2). It has been suggested that the hypoxic zone results from water column stratification driven by weather and river flow combined with the decomposition of organic matter in bottom waters (Rabalais et al. 2002). River-borne organic matter along with the nutrients needed for phytoplankton growth enter the Gulf of Mexico via Mississippi River system discharge. Annual variability in the area of the hypoxic zone has been related to the rate of outflow of the Mississippi and Atchafalaya rivers, which is controlled by precipitation patterns that influence riverine discharge rates. The record of algal production preserved in sediment cores from the hypoxic zone show that algal production during the first half of the twentieth century in the Gulf of Mexico shelf was significantly lower, suggesting that anthropogenic changes to the basin and its discharges have increased the frequency and intensity of hypoxic events (CENR 2000; USEPA 2004). Since 1980, the basin's annual riverine discharge to the Louisiana shelf was estimated to be approximately 1.8 million metric tons (2 million tons) of nitrogen/year. It has been estimated that total nitrate-nitrogen flux tripled from the 1960s and 1970s to the 1980s and 1990s. More than half of this flux comes from non-point sources from the drainage of agricultural lands north of the confluence of the Ohio and Mississippi Rivers (CENR 2000). Gulf of Mexico continental shelf ecosystems and fisheries are affected by the hypoxia, with

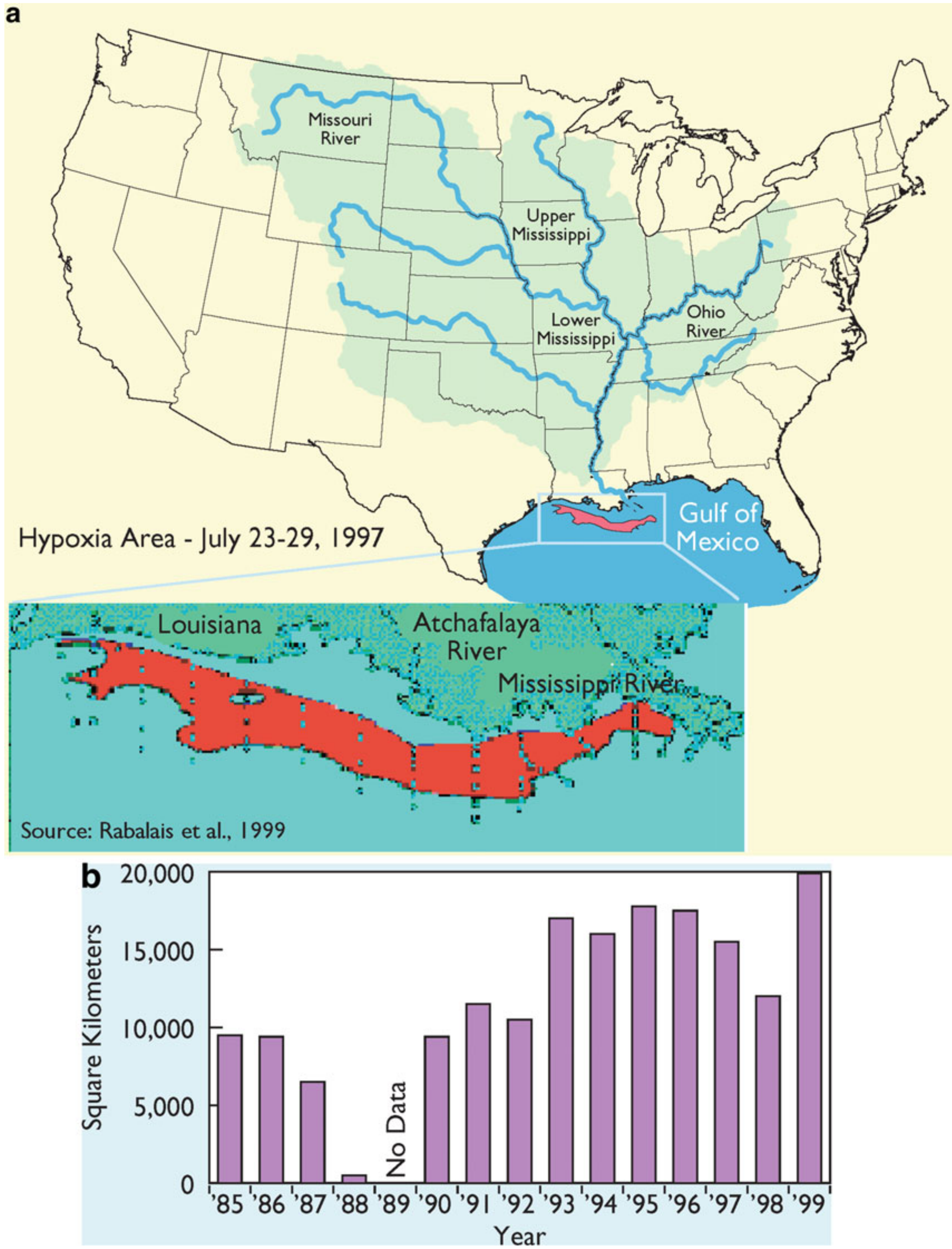

Figure 2.77. Hypoxic zone's (a) extent in 1997; (b) areal extent from 1985 to 1999; (c) spatial extent during July 1999, 2000, 2001; and (d) spatial extent of the Gulf Coast in July 2000, 2001, and 2002 (modified from USEPA 2001, 2004, 2008).

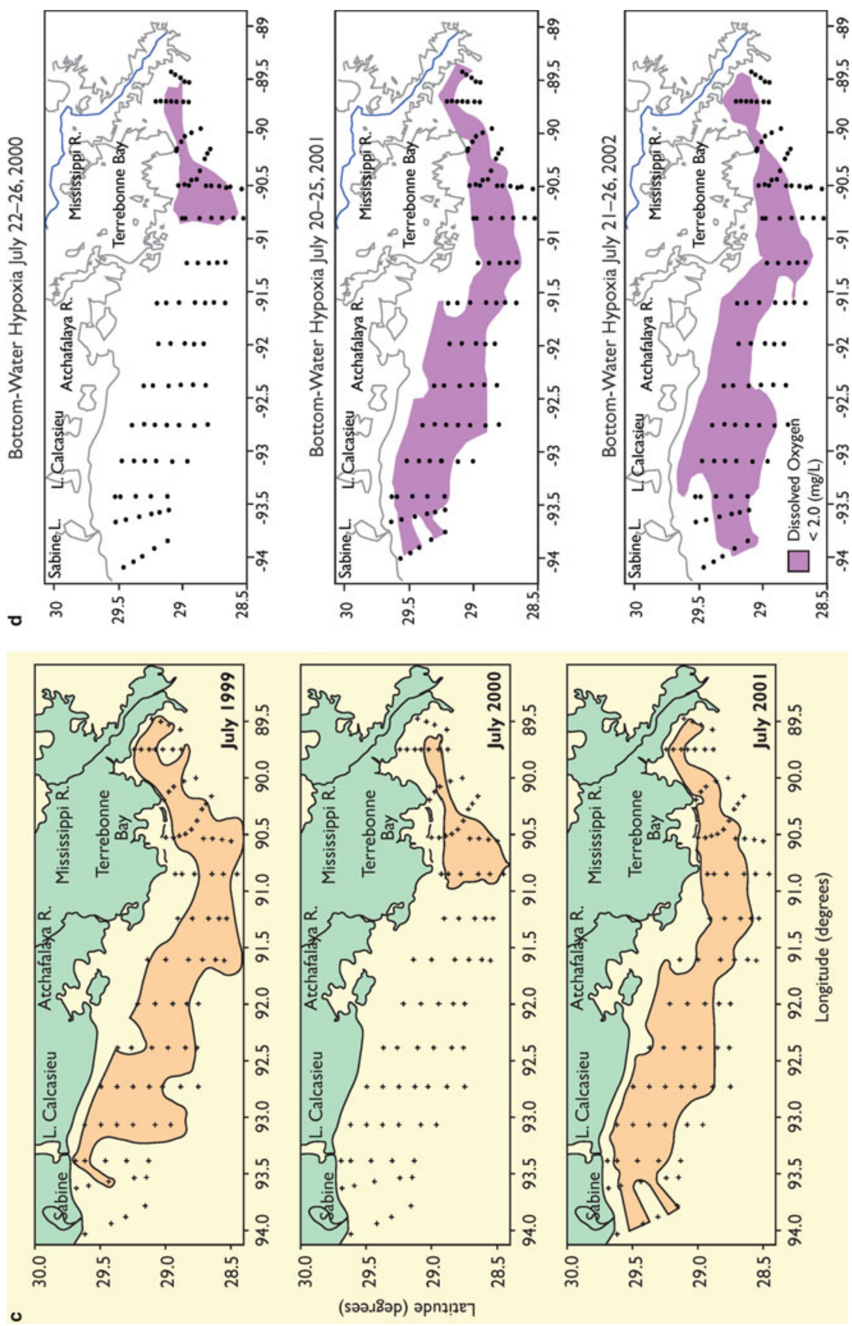

Figure 2.77. (continued)

mobile organisms trying to physically avoid the hypoxic zone. These hypoxic events are the most widespread example of degraded water quality in the offshore regions of the northern Gulf of Mexico.

2.4.2 Continental Shelf/Slope and Abyssal Water Quality and Contaminants

Contaminants have the potential to affect water quality in continental shelf/slope and abyssal environments but that potential is limited. In most instances, contaminants originate on land, in coastal estuaries, and/or are delivered to the coast in the inflows of river systems and runoff. In most instances contaminant concentrations tend to rapidly decrease with distance offshore. The major exception to this generality is petroleum contamination. In the continental shelf/slope and abyssal regions of the northern Gulf of Mexico, most petroleum contamination has been introduced by natural processes (i.e., oil and gas seepage). The vast majority of chemical contaminants, other than petroleum, are found in coastal areas where human activities are concentrated. However, contaminants can be introduced directly to the offshore by atmospheric deposition (e.g., mercury), disposal of drill muds and cuttings (e.g., petroleum and a suite of metals, mostly barium from drilling muds), discharge of produced waters (e.g., petroleum and trace amounts of metals), and the use and disposal of chemicals on oil and gas platforms and ships (e.g., local use of pesticides). On occasion, contaminants in coastal areas can persist and be transported to more distant offshore locations by ocean currents. Based on these considerations, expectations are that if contaminants other than petroleum are present in continental shelf/slope and abyssal waters, the concentrations in water would be exceedingly low and have little or no implications for offshore water quality. Other than the monitoring of contamination-associated discharges of drill cuttings and produced water at oil and gas platforms, few studies have measured chemical contaminants in offshore, northern Gulf of Mexico environments. On occasion, contaminants have been detected in sediments and biological tissues within a few hundred meters of oil and gas platforms. For petroleum contaminants the situation is quite different.

As previously noted, the most comprehensive and recent report on the sources and annual mass loadings of petroleum to U.S. marine environments is NRC's *Oil in the Sea III*: *Inputs*, *Fates*, *and Effects* report (NRC 2003). Those aspects of the NRC report relevant to understanding the impact of petroleum contamination on water quality have been provided in the introduction to this chapter and during consideration of petroleum contamination in coastal areas (Sections 2.2.5 and 2.3.7). The following assessments of petroleum in continental shelf/slope and abyssal environments are based on the NRC summary of data for 1990–1999. As before, the 9-year averages are considered representative of longer-term trends, and the loadings estimated in the NRC (2003) report for various sources of releases are expected to, and do, vary with time. The mass loadings of average annual petroleum inputs to the offshore Gulf of Mexico for 1990–1999 are summarized in Table 2.8 (NRC 2003). The conclusions reached in the following assessment of petroleum contamination in the continental shelf/slope and abyssal waters are subject to the limitations discussed in the introduction (e.g., mass loadings reflect the intensity and location of petroleum usage but do not directly indicate biological or ecological impact). Petroleum contamination has rarely been identified as a primary cause of the degradation of continental shelf/slope and abyssal water quality except in instances such as a major oil spill.

The Gulf of Mexico is prolific in oil and gas provinces and has been the site of exploration and extraction activities for many decades (Figures 2.45 and 2.46, Section 2.3.7). Current oil and gas exploration and production is concentrated in the deep water of the Gulf of

Table 2.8. Average Annual Mass Loadings of Petroleum (tonnes) to the Offshore Gulf of Mexico, 1990–1999 (modified from NRC 2003) (1 tonne = 1 metric ton(ne) = 1.102 U.S. short tons; 1 gigatonne = 1 billion tonnes)

Zone (offshore)	North Central/ Northeastern	North Central/ Northwestern	South Central/ Southwestern
Sum seeps[a]	*70,000*	*70,000*	*na*[a]
Platforms	Trace[b]	50	61[c]
Atmospheric	Trace	60	40
Produced	Trace	1,700	130
Sum extraction	*Trace*	*1,800*	*231*
Pipelines	Trace	60	nd[d]
Tank vessel	10	1,500	nd[d]
Atmospheric	Trace	Trace	Trace
Sum transportation	*10*	*2,400*	*90*
Land-based[e]	na	na	na
Recreational vessels[f]	na	na	na
Vessels > 100 gigatonnes (spills)	70	120	Trace
Vessels > 100 gigatonnes (op discharge)	Trace	25	Trace
Vessels < 100 gigatonnes (op discharge)	Trace	Trace	Trace
Atmospheric	1,600	1,200	3,600
Aircraft[g]	80	80	20
Sum consumption	*1,800*	*1,400*	*3,600*

[a]No known seeps in these regions
[b]Estimated loads of less than 10 tonnes per year reported as "trace"
[c]Lack of precise locations for platforms in this zone precluded determining whether spills or other releases occurred less than 3 mi from shore, thus all values for this zone reported as "offshore"
[d]No information on the existence of coastal facilities was available for this region
[e]Land-based inputs are defined in this study as being limited to the coastal zone
[f]Recreational vessels are defined as being limited to operation with 3 mi of the coast
[g]Purposeful jettisoning of fuel not allowed within 3 mi of land

Mexico. Activities associated with the extraction, transportation, and consumption of petroleum have the potential to release petroleum to offshore water environments (Section 2.3.7.2 and Figures 2.49 and 2.50).

Petroleum inputs to the offshore Gulf of Mexico have a very different mix of sources and annual loadings when compared to coastal waters (Figure 2.78) (NRC 2003). In the offshore region, annual mass loadings of petroleum from natural oil and gas seeps were estimated to be 70,000 tonnes (77,162 tons) each for the northwestern and northeastern (almost all offshore Louisiana) offshore Gulf of Mexico in the 1990s (Table 2.8). Oil and gas seepage has been a feature of the Gulf of Mexico for thousands if not tens of thousands of years, so these estimates are not subject to the temporal fluctuations that are expected for anthropogenic releases of petroleum. The major uncertainties in petroleum loadings to the Gulf of Mexico are the accuracies of the methods used to make estimates. These estimates can have quite large uncertainties and vary depending on the estimation method. One single source contributed approximately 95 % of the petroleum input to the offshore northern Gulf of Mexico during the 1990s. Since most oil and gas platforms are located offshore Texas and Louisiana, releases related to extraction facilities were negligible in the northeastern Gulf of Mexico while 1,800

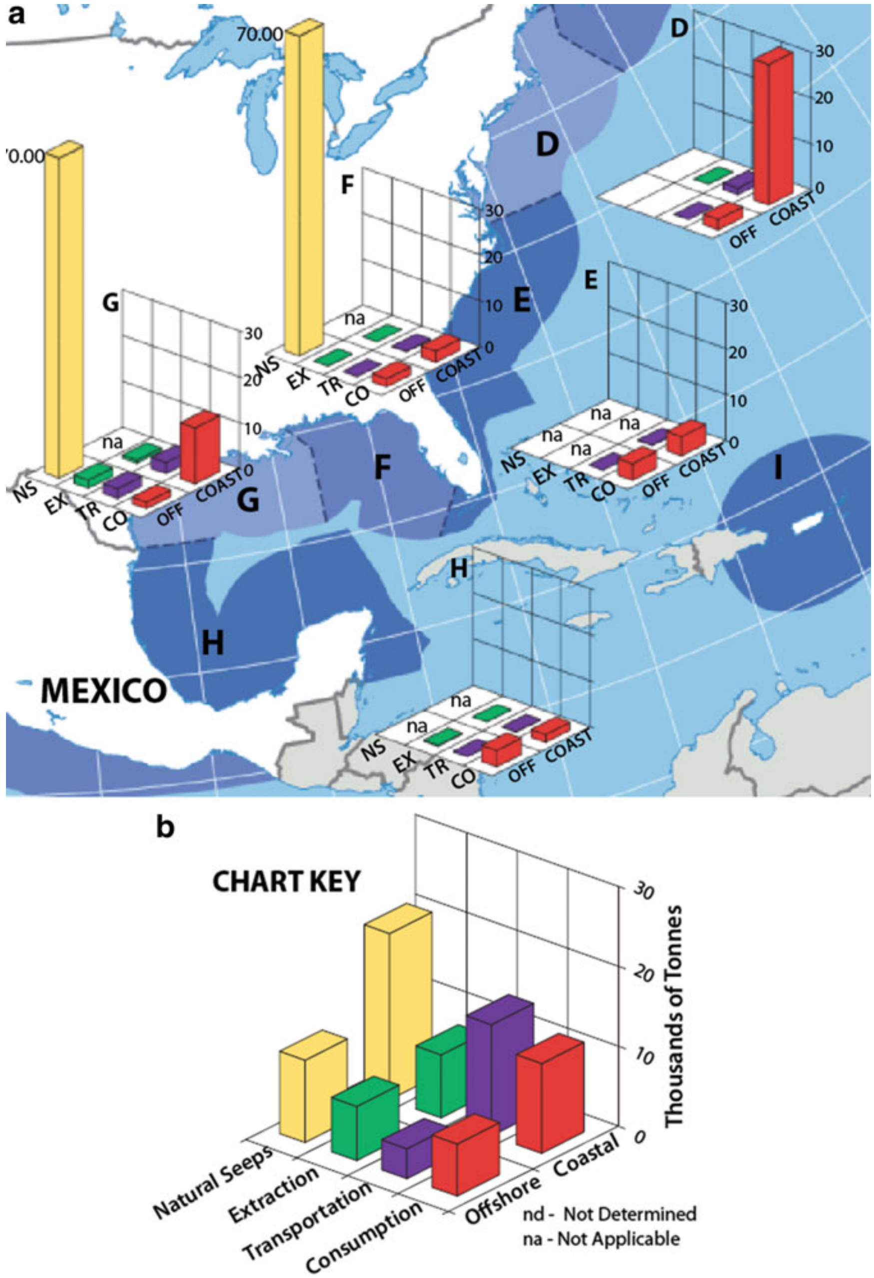

Figure 2.78. Variation in average annual input (thousands of tonnes) of petroleum to the marine environment in the Gulf of Mexico from 1990 to 1999 (*yellow* natural seeps, *green* extraction, *purple* transportation, *red* consumption) (modified from NRC 2003).

tonnes (1,984 tons) annually entered the northwestern Gulf of Mexico during the 1990s. Almost all of this petroleum release came from produced water discharges (Table 2.8). For comparison, the same inputs from extraction activities and produced water discharges were negligible amounts with 680 tonnes (750 tons) of petroleum released to northeastern and northwestern coastal waters combined during the same time period. Similarly, since most platforms and shore-based refineries and chemical complexes are in the northwestern Gulf of Mexico, 10 and

1,600 tonnes (11 and 1,764 tons) of petroleum were annually released by transportation activities to the offshore northeastern and northwestern Gulf of Mexico, respectively, in the 1990s (Table 2.8). For comparison, the same inputs for northeastern and northwestern coastal waters were 160 and 2,400 tonnes (176 and 2,646 tons), respectively. Annual mass loadings of petroleum related to consumption activities in the offshore northeastern and northwestern Gulf of Mexico were 1,800 and 1,400 tonnes (1,984 and 1,543 tons), respectively, during the 1990s (Table 2.8). For comparison, the same inputs were 2,500 and 12,000 tonnes (2,756 and 13,228 tons) for northeastern and northwestern coastal waters, respectively, from 1990 to 1999. This reflects the concentration of consumption activities in coastal waters, particularly in the northwestern Gulf of Mexico. A graphical summary of this information is displayed in Figure 2.78. The dominance of natural oil and gas seepage as a source of petroleum contamination in the Gulf of Mexico in general and in the offshore as compared to the coastal regions is evident.

Comparing overall petroleum loadings in the Gulf of Mexico as natural or anthropogenic annual loadings in the 1990s:

- 140,000 tonnes total *natural* annual loadings
  - 70,000 tonnes northeastern Gulf of Mexico annual loadings
  - 70,000 tonnes northwestern Gulf of Mexico annual loadings
- 25,400 tonnes total *anthropogenic* annual loadings
  - 4,400 tonnes northeastern Gulf of Mexico annual loadings
  - 21,000 tonnes northwestern Gulf of Mexico annual loadings

The same inputs for coastal Gulf of Mexico waters:

- Negligible total *natural* annual loadings
- 17,740 tonnes total *anthropogenic* annual loadings
  - 2,660 tonnes northeastern Gulf of Mexico annual loadings
  - 15,080 tonnes northwestern Gulf of Mexico annual loadings

Based on these summaries of petroleum releases to the offshore Gulf of Mexico during the 1990s, the magnitude of the annual mass loadings for natural oil and gas seepage suggests that this source of petroleum has the greatest potential to affect continental shelf/slope and abyssal water quality. The most likely indicator of water quality to be affected is dissolved oxygen concentrations. As seeping oil and gas transits through the water column, the water directly above oil and gas seeps can exhibit lowered oxygen concentrations due to aerobic microbial oxidation of hydrocarbons. Due to the well-mixed nature of the bottom waters overlying the Gulf of Mexico continental shelf and slope, these effects are usually restricted to a few meters or less of the water column above the sediment/water interface. Hydrocarbon gases often form plumes that can persist in the water column meters above seep locations. At individual seep sites, degradation of water quality appears to be spatially limited and ephemeral. In the offshore regions oxygen-rich deep waters from the Atlantic Ocean flow into the Gulf of Mexico from the Caribbean Sea with the major outflow being the Florida Straits (Jochens et al. 2005). The sources of dissolved oxygen in the upper waters (approximately 100–200 m [328–656 ft]) of the Gulf of Mexico are the atmosphere and photosynthesis, with wind and wave action controlling air-sea gas exchange. The depth to which photosynthesis occurs in the upper layers of the Gulf of Mexico depends on light penetration and nutrient concentrations. The source of dissolved oxygen in the deep waters of the Gulf of Mexico is the transport and mixing of oxygen-rich water from the Caribbean Sea delivered by currents via the Yucatán Channel. Deep oceanic circulation and the associated mixing are the only processes that replenish deepwater oxygen. The major sink for oxygen in the Gulf of Mexico, as in the world's oceans, is oxidation of organic matter. Organic matter consists of living organisms, detritus from living organisms (fecal pellets, secretions, dead organisms, etc.), continental detritus washed into the ocean via river runoff and in the Gulf of Mexico, petroleum. An oxygen minimum zone occurs in the Gulf of Mexico between 300 and 700 m (985 and 2,297 ft) due to the depletion of dissolved oxygen by processes occurring outside of the Gulf of Mexico and the decay of organic matter within Gulf of Mexico sediments and waters. The productivity of the Gulf of Mexico is not high enough to create extreme oxygen minimum zones as observed in other locations in the world's oceans. Other than the continental shelf hypoxia zones discussed above, dissolved oxygen concentrations indicate good water quality for continental shelf/slope and abyssal waters in the Gulf of Mexico. The impact of oil and gas seeps on dissolved oxygen concentrations was found to be negligible in the deep water of the Gulf of Mexico while localized effects might be measurable (Jochens et al. 2005). Although natural seepage of oil and gas into the Gulf of Mexico has been occurring for thousands of years, continental shelf/slope and abyssal water dissolved oxygen concentrations show no significant perturbations attributable to the presence of petroleum from natural seeps. As described above, localized low oxygen conditions have been reported in close proximity to the sediment/water interface at seep sites.

The other source of petroleum contamination to the offshore Gulf of Mexico that has the potential to affect continental shelf/slope and abyssal water quality is the massive volumes of discharged production waters from the many oil and gas platforms. The discharge of produced waters into the offshore waters of Louisiana and Texas is extensive (Figure 2.79). Estimates of produced waters discharged into outer continental shelf (OCS) waters of the northwestern Gulf were approximately 500×10^6 barrels per year (bbl/year) (21×10^9 gallons per year [gal/year]) with the majority of discharges occurring offshore of Louisiana (Rabalais et al. 1991). A more recent estimate (NRC 2003) indicated approximately 500×10^6 bbl/year (21×10^9 gal/year) for the OCS across the Gulf with an additional approximately 200×10^6 bbl/year (8.4×10^9 gal/year) for Louisiana territorial waters and approximately 4×10^6 bbl/year (167×10^6 gal/year) for Texas territorial waters for a total for the Gulf of Mexico of approximately 660×10^6 bbl/year (27.7×10^9 gal/year) of discharged produced waters. The offshore total volumes from the two estimates are similar. The amount of produced water generated increases as oil or gas fields are depleted and may be as high as 95 % of the product stream in older fields such as those offshore of Louisiana and Texas. A study directed at estimating the contribution of platform discharges on the hypoxic zone gives insight into the contribution of these point sources of pollution to the overall quality of continental shelf/slope and abyssal waters (Rabalais 2005). Organic carbon in produced waters has the potential to be degraded by aerobic microbes reducing dissolved oxygen concentrations. Nitrogen, mostly in the form of ammonium, has the potential to stimulate phytoplankton production some of which may be decomposed contributing to respiratory demand for oxygen. The amounts of organic carbon and ammonium (labile nitrogen) in produced water discharges were compared to those delivered by the Mississippi and Atchafalaya rivers. It was estimated that the contribution of carbon and nitrogen found in produced water discharges were minimal compared to riverine inputs (0.013 % of the total nitrogen delivered by the Mississippi River system, 0.008 % of the total DIN, and 0.002 % of the total ammonium at the time of the study). Petroleum discharged in production waters, measured as oil and grease, was minor compared to the Mississippi River input. The produced water contribution of organic carbon to the Gulf of Mexico hypoxic area was judged to be insignificant. Over the years discharges from platforms have been regulated and reduced, lowering the potential for degrading water quality even further. The USEPA Best Available Treatment Technology Economically Achievable for the National Pollutant Discharge Elimination System (NPDES) permit restricts the concentration of petroleum, measured as oil and grease, in produced water destined for ocean disposal to a monthly average of 29 mg/L (USEPA 1993). Produced waters must also meet toxicity criteria before discharge is allowed.

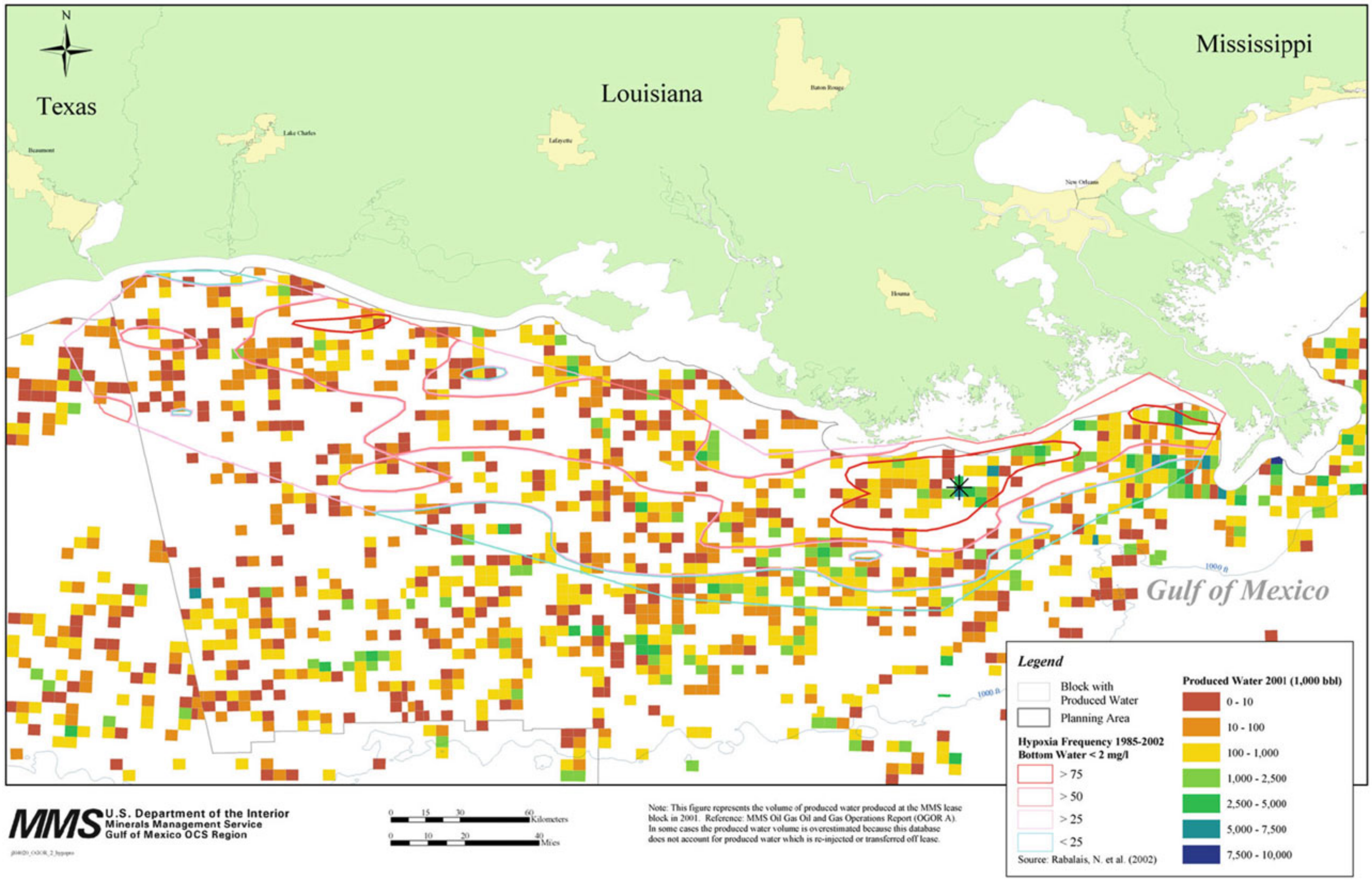

Figure 2.79. Distribution of produced water discharge volumes by OCS lease block for a portion of the Central and Western OCS superimposed on the frequency of midsummer, bottom-water hypoxia (modified from a map generated by the Minerals Management Service with input from Rabelais, 2005 for the distribution of hypoxia frequency).

The conclusion is that produced water discharges have minimal impact on water quality in the offshore regions of the Gulf of Mexico, and any effects that might be observed would be localized at discharge points and ephemeral.

As previously noted, non-petroleum contaminants also have the potential to degrade water quality; however, most monitoring programs only measure non-petroleum contaminants in sediments and biological tissues. Little information is available on the ambient concentrations of these chemicals in offshore waters though they are expected to be low. The concentrations of these chemicals in coastal waters are, in most instances, below the detection limits of standard analytical protocols, and it is reasonable to assume that concentrations in offshore water would be even lower. In several studies, contaminant concentrations in organism tissues collected close to offshore platforms not only contained no detectable petroleum, they also contained no detectable non-petroleum contaminants. Most non-petroleum contaminants result from chronic use of chemicals on land or the adjacent coastal areas. These influences are rapidly diminished seaward of source areas in coastal regions. The distance from the release point and the expected dilution with uncontaminated offshore waters further offshore suggest that non-petroleum contaminants do not degrade continental shelf/slope and abyssal water quality. However, some contaminants, such as those transported long distances by atmospheric (e.g., mercury) or oceanic processes and those contaminants that bioaccumulate and biomagnify, may be found in offshore marine organisms and sediments.

Continental shelf/slope and abyssal waters in the Gulf of Mexico are subjected to a variable mix of inputs that have the potential to degrade water quality. However, in most instances, no significant degradation of water quality has been observed, with one major exception—the input of nutrients from the Mississippi River system degrading water quality on the northwestern/central continental shelf. In offshore areas, natural oil and gas seeps are by far the dominant sources of petroleum loadings, but evidence is lacking that this has resulted in significant degradation of offshore water quality. The largest offshore source of anthropogenic petroleum contamination in the eastern Gulf of Mexico is spills from tank vessels. In the western Gulf of Mexico, it is produced water discharges, but the loading of petroleum from natural oil and gas seepage dwarfs these inputs. Petroleum inputs from activities associated with extraction, transportation, and consumption are chronic but low and widely geographically dispersed. These petroleum releases most often occur at the sea surface, which suggests that ambient water concentrations rapidly decrease due to dilution with uncontaminated waters. These factors account for a lack of observations of degraded water quality on the continental shelf/slope and abyss of the Gulf of Mexico. Similarly, waterborne biological contaminants (pathogens) are discharged almost exclusively in coastal areas (the exceptions being ship and platform sewage disposal). The viability of pathogens in seawater is limited, which reduces the possibility of long distance transport. Also, the effects of biological contaminants on water quality in deeper water regions of the northern Gulf of Mexico are expected to be negligible.

2.5 SUMMARY

The patterns and trends in water quality in the Gulf of Mexico are complex and variable in space and time. Assessments performed over more than two decades have concluded that water quality in a majority of estuaries and coastal environments along the northern Gulf of Mexico coast is highly influenced by human activities. One of the most prevalent causes of degraded water quality in the coastal areas of the Gulf of Mexico is excessive levels of anthropogenic nutrients that create widespread coastal eutrophication. Eutrophication lowers dissolved oxygen concentrations, increases chlorophyll *a* concentrations, diminishes water clarity, and can lead to toxic/nuisance algal blooms and loss of submerged aquatic vegetation. While variable over time, overall ecological conditions in Gulf estuaries have been judged as fair to poor, and assessments consistently have concluded that water quality is fair. In some locations, water quality appears to be improving due to environmental regulations and controls; at other sites, conditions have deteriorated. The status of and trends in water quality are highly site specific. Many Gulf of Mexico coastal environments exhibit high levels of eutrophication. Chlorophyll *a* concentrations are high, particularly along the coasts of western Florida, Louisiana, and lower Texas. Epiphytes (a variety of organisms that grow on other plants including submerged aquatic vegetation) and macroalgal abundances are moderate to high at a number of locations. Low dissolved oxygen concentrations have been routinely observed particularly along the Florida coast and in the Mississippi River Plume. The loss of submerged aquatic vegetation is a problem in many estuaries and nuisance/toxic algal blooms are pervasive in many estuaries especially in Florida, western Louisiana and the lower Texas coast. High levels of eutrophication have resulted in increased turbidity associated with high concentrations of chlorophyll *a*, low levels of dissolved oxygen, moderate to high levels of nuisance/toxic algal blooms and epiphyte abundances, and ultimately the loss of submerged aquatic vegetation. The few improvements observed over time are attributed to better management of point and non-point sources of nutrients. The intensity of human activities correlates with high eutrophication, though in many instances, impairment of use has been difficult to directly or solely relate to eutrophication or water quality. Comparing 1999 and 2007 assessments, eutrophication conditions worsened in one system and improved in another. A trend analysis was not possible because indicators were not always comparable. In one study, 13 of the 38 Gulf of Mexico estuaries studied were predicted to develop worsening conditions in the future. Factors expected to influence future trends in water quality were control and mitigation of urban runoff, wastewater treatment, industrial expansion, atmospheric deposition, animal operations, and agriculture activities. There were no estuaries where conditions were expected to improve and worsening conditions were predicted in all systems for which data were available (Bricker et al. 1999). Trends in human population distributions, accelerating development pressures, and human-associated activities were the main factors suggesting water quality will worsen in the future.

In regard to the effect of chemical pollutants on water quality, direct measurements of pollutants dissolved in marine waters are limited. While chemical contaminants can, and probably do, make limited contributions to degraded water quality, especially in coastal areas where concentrations are highest, these impacts are masked by the overwhelmingly dominant factor that degrades water quality—eutrophication. The northwestern Gulf of Mexico experiences some of the largest average annual inputs of petroleum to North American marine waters as a result of the high volumes of tanker traffic, the large numbers of oil and gas platforms, the contaminated inflows from the Mississippi River, and the occurrence of natural oil and gas seeps. Indirect indications of possible impacts of chemical contaminants on water quality include the detection of contaminants in biological tissues and sediments. Elevated tissue concentrations of total PCBs, DDT, dieldrin, mercury, cadmium, and toxaphene have been detected in fish tissue. However, contaminants accumulate in biological tissues via pathways other than uptake from water. Fish consumption advisories due to mercury contamination have been common along the northern Gulf of Mexico, and beaches have been routinely closed or under advisories due to elevated levels of bacteria. Once outside the influence of coastal processes, water quality is good and has been good for a long time in the Gulf of Mexico. Exceptions are hypoxic zones on the shelf, waters just above natural oil and gas seeps, and localized and ephemeral effects on water quality due to the discharge of produced waters. However, continental shelf/slope and abyssal Gulf of Mexico waters remain mostly unimpaired by human activities primarily due to the relatively low levels of pollutant discharges and the dilution due to the large volume and mixing rates of receiving waters. Coastal Gulf of Mexico water quality is highly influenced by humans and will continue to be for the foreseeable future.

In large part, future trends in water quality will be dependent on the decisions made by the populations that live, recreate, and work along the northern Gulf of Mexico coast in regard to controlling and/or mitigating those factors that degrade water quality.

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APPENDIX A

Table A.1. Summary of Methodologies for Judging Water Quality in Various Monitoring Programs in the Gulf of Mexico (most of these descriptions are taken verbatim from the reference indicated)

Information	Details
National estuarine eutrophication assessment: effects of nutrient enrichment in the nation's estuaries (Bricker et al. 1999)	
Data sources	The assessment was based primarily on the results of the National Estuarine Eutrophication Survey, conducted by NOAA from 1992 to 1997 supplemented by information on nutrient inputs, population projections, and land use drawn from a variety of sources (full report at http://ian.umces.edu/neea/pdfs/eutro_report.pdf, accessed June 21, 2015)
Methodology	A numerical scoring system was developed to integrate information on (1) primary symptoms: decreased light availability (chlorophyll *a* concentrations and problematic epiphytic and macroalgal growth), algal dominance (diatom/dinoflagellate ratios and benthic to pelagic dominance ratios), and increased organic matter decomposition (chlorophyll *a* concentrations and problematic macroalgal growth) and (2) secondary symptoms: loss of submerged aquatic vegetation (spatial coverage and trends), harmful algae (nuisance and toxic blooms), and low dissolved oxygen (anoxia, hypoxia, and stress) to determine the overall status of eutrophic symptoms in each estuary. This scoring system was implemented in three phases according to the methods described in detail the report First, a single index value was computed from all primary symptoms. The scoring system gave equal weight to all three symptoms and considered the spatial and temporal characteristics of each. The scores for the three symptoms were then averaged, resulting in the highest values being assigned to estuaries having multiple primary symptoms that occur with great frequency, over large spatial areas of the estuary, and for extended periods of time. Likewise, the lowest scores indicate estuaries that exhibit few, if any, characteristics of the primary symptoms Next, a single index value was computed from all secondary symptoms. The scoring system again gave equal weight to all symptoms and their spatial and temporal characteristics. The highest score of any of the three symptoms was then chosen as the overall secondary value for the estuary. This weights the secondary symptoms higher than the primary symptoms, because the secondary symptoms take longer to develop, thereby indicating a more chronic problem, and being more indicative of actual impacts to the estuary Finally, the range of numeric scores assigned to primary and secondary symptoms was divided into categories of high, moderate, and low. Primary and secondary scores were then compared in a matrix so that overall categories could be assigned to the estuaries Estuaries having high scores for both primary and secondary conditions were considered to have an overall "high" level of eutrophication. Likewise, estuaries with low primary and secondary values were assigned an overall "low" level of eutrophication. Scores were then assigned to the remaining estuaries based on interpretations of each estuary's combined values
National Coastal Condition Report (NCCR I) (USEPA 2001)	
Data sources	Coastal monitoring data from programs like EMAP and NOAA National Status and Trends (NS&T) Assessment and advisory data provided by states or other regulatory agencies and compiled in national databases (full report at http://water.epa.gov/type/oceb/assessmonitor/nccr/downloads.cfm, accessed June 21, 2015)

(*continued*)

Table A.1 (continued)

Information	Details
Methodology	Overall condition for each coastal area was calculated by summing the scores for indicators and dividing by the number of indicators, where good = 5, fair = 3, and poor = 1. Characterizing coastal area (water quality indicators water clarity and dissolved oxygen) involves two value determinations. The first value is the definition of "poor" for an indicator. The definition of poor condition for each indicator is based on existing criteria, guidelines, and/or interpretation of scientific literature. The percent areas used for each indicator are value judgments and were largely determined by informally surveying environmental managers, resource experts, and the knowledgeable public
Water clarity	EMAP-Estuaries (EMAP-E) estimates water clarity by comparing the amount and type of light reaching the water surface to the light at a depth of 1 m. Water clarity is considered poor if less than 10 % of surface light reaches 1 m. The water clarity data were collected by the EMAP-E program unless otherwise noted. This measure is used to determine water quality as follows: good—less than 10 % of the coastal waters have poor light penetration, fair—10–25 % of the coastal waters have poor light penetration, and poor—more than 25 % of the coastal waters have poor light penetration
Dissolved oxygen	Dissolved oxygen (DO) is a fundamental requirement for all estuarine life. A threshold concentration of 4–5 ppm (five parts of oxygen per million parts of water) has been used by many states to set water quality standards. Concentrations below ~2 ppm are thought to be stressful to many estuarine organisms. These low levels most often occur in bottom waters and impact the organisms that live in the sediments. Low levels of oxygen (hypoxia) or lack of oxygen (anoxia) often accompany the onset of bacterial degradation, sometimes resulting in the presence of algal scums and noxious odors. In some estuaries, low levels of oxygen, at least periodically, are part of the natural ecology. Therefore, it is difficult to interpret whether the observed effects are natural or human induced. The DO data were collected under the EMAP-E program unless otherwise noted. This indicator is used to measure water quality as follows: good—less than 5 % of the coastal waters have less than 2 ppm DO, fair—5–15 % of the coastal waters have less than 2 ppm DO, and poor—more than 15 % of the coastal waters have less than 2 ppm DO
Eutrophication index	Eutrophication due to the accelerated input of nitrogen and phosphorus can promote a complex array of symptoms such as excessive growth of algae that may lead to other problems. For its National Estuarine Eutrophication Assessment, NOAA developed a system that evaluates several symptoms of eutrophication in an estuary to provide a single categorical value to represent the status of overall eutrophic condition for each estuary (Bricker et al. 1999). This value is the measure of eutrophic condition presented in this report. The primary symptoms examined for this value are chlorophyll *a*, macroalgal abundance, and epiphyte abundance. Secondary symptoms include loss of submerged aquatic vegetation, harmful algae, and low dissolved oxygen. This indicator is used to measure water quality as follows: good—less than 10 % of the coastal waters have symptoms indicating a high potential for eutrophication, fair—10–20 % of the coastal waters have symptoms indicating a high potential for eutrophication, and poor—more than 20 % of the coastal waters have symptoms indicating a high potential for eutrophication

(*continued*)

Table A.1 (continued)

Information	Details
Designated or desired uses	The following programs maintain databases repositories for information about how well coastal waters support their designated or desired uses. These uses are important factors in public perception of the condition of the coast and also say a lot about the condition of the coast as it relates to public health *Clean Water Act Section 305*(*b*) *and 303*(*d*) *Assessments*—States report water quality assessment information and water quality impairments under Sections 305(b) and 303(d) of the Clean Water Act. Water quality standards include narrative and numeric criteria that support specific designated uses and also specify goals to prevent degradation of good quality waters. Numeric criteria are used to evaluate whether the designated uses assigned to water bodies are supported. Data is consolidated into general categories. The most common designated uses are: aquatic life support; drinking water supply; recreation (such as swimming, fishing, and boating); and fish consumption. After comparing water quality data to the criteria set by water quality standards, waters are placed into the following categories: fully supporting—these waters meet applicable water quality standards, both criteria and designated use; threatened—these waters currently meet water quality standards, but states are concerned they may degrade in the near future; partially supporting—these waters meet water quality standards most of the time, but exhibit occasional exceedances; and not supporting—these waters do not meet water quality standards *Beach Closures*—There is growing concern about public health risks posed by polluted bathing beaches. Scientific evidence has documented a rise of infectious diseases caused by microbial organisms in recreational water. A primary goal of USEPA's Beaches Environmental Assessment, Closure, and Health (BEACH) Program, established in 1997, is to work to compile information on beach pollution to define the extent of the problem. A few states have comprehensive beach monitoring programs, many other states have only limited beach monitoring programs
National Coastal Condition Report (NCCR II) (USEPA 2004)	
Data sources	This report examined data sets from different agencies and areas of the country. Three types of data were presented in this report: coastal monitoring data from programs such as USEPA's EMAP and the NCA Program, NOAA's NS&T Program, and USFWS's National Wetlands Inventory (NWI); fisheries data for Large Marine Ecosystems (LMEs) from the National Marine Fisheries Service (NMFS), and assessment and advisory data provided by states or other regulatory agencies and compiled in national databases (full report at http://water.epa.gov/type/oceb/2005_index.cfm, accessed June 21, 2015)
Methodology	Five primary indices were created using data from national coastal programs: water quality index, sediment quality index, benthic index, coastal habitat index, and fish tissue contaminants index. These indices were selected because of the availability of relatively consistent data sets for these indicators. These indices do not address all characteristics of estuaries and coastal waters that are valued by society, but they do provide information on both ecological condition and human use of estuaries Characterizing coastal areas using each of the five indicators involved two steps. The first step was to assess condition at an individual site for each indicator. For each indicator, site condition rating criteria are determined based on existing criteria, guidelines, or the interpretation of

(*continued*)

Table A.1 (continued)

Information	Details
	scientific literature. The second step was to assign a regional rating for the indicator based on the condition of individual sites within the region. The regional criteria boundaries (i.e., percentages used to rate each regional condition indicator) were determined as a median of responses provided through a survey of environmental managers, resource experts, and the knowledgeable public. Evaluations for fish tissue contaminants were used to assess human use attainment The results of evaluations of estuarine condition were used to assess aquatic life use and human use attainment. If any of four indicators of condition—water quality condition, sediment quality, benthic condition, or habitat loss—received a poor rating at a given site, then the site was assessed as impaired for aquatic life use. Threatened aquatic life use was assessed as the overlap of fair conditions of these same indicators. A site was determined to be unimpaired for aquatic life use if all four indicators were rated good, or only one indicator was rated fair and no indicators were rated poor. Spatial areas were assigned a category of (1) impaired for aquatic life use only, (2) impaired for human use only, (3) impaired for both aquatic life use and human use, (4) threatened (for one or both uses), or (5) unimpaired (for both uses)
Water quality index	The water quality index consisted of five indicators: nitrogen, phosphorus, chlorophyll *a*, water clarity, and dissolved oxygen. The water quality index used in this report was intended to characterize acutely degraded water quality conditions. It did not consistently identify sites experiencing occasional or infrequent hypoxia, nutrient enrichment, or decreased water clarity. As a result, a rating of poor for the water quality index means that the site is likely to have consistently poor condition during the monitoring period. If a site is designated as fair or good, the site did not experience poor condition on the date sampled, but could be characterized by poor condition for short time periods. In order to assess the level of variability in the index at a specific site, increased or supplemental sampling is needed. DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen were assessed for a given site (see below), the water quality index rating was calculated for the site based on these five indicators as: <u>good</u> if a maximum of one indicator is fair, and no indicators are poor; <u>fair</u> if one of the indicators is rated poor, or two or more indicators are rated fair; <u>poor</u> if two or more of the five indicators are rated poor; and <u>missing</u> if two components of the indicator are missing, and the available indicators do not suggest a fair or poor rating
Nutrients: nitrogen and phosphorus	DIN and DIP were determined chemically through the collection of filtered surface water at each site. DIN and DIP reference surface concentrations used to assess condition in this report were generally lower than those in the NOAA report because of the natural reduction in nutrient concentrations due to uptake by phytoplankton from spring to summer for the production of chlorophyll. Ratings for coastal monitoring sites in the Gulf of Mexico were for DIN concentrations: <u>good</u>—$<$0.1 mg/L, <u>fair</u>—0.1–0.5 mg/L and <u>poor</u>—$>$0.5 mg/L and for DIP concentrations: <u>good</u>—$<$ 0.01 mg/L, <u>fair</u>—0.01–0.05 mg/L and <u>poor</u>—$>$0.05 mg/L. For regionals scores both DIN and DIP concentrations were: <u>good</u> if less than 10 % of the coastal area was in poor condition, and more than 50 % of the coastal area was in good condition; <u>fair</u> if 10–25 % of the coastal area was in poor condition, or more than 50 % of the coastal area was in combined poor and fair condition; and <u>poor</u> if more than 25 % of the coastal area was in poor condition

(*continued*)

Table A.1 (continued)

Information	Details
Chlorophyll *a*	Surface concentrations of chlorophyll *a* were determined from a filtered portion of water collected at each site and rating for coastal monitoring sites in the Gulf of Mexico were for chlorophyll *a* concentrations; good—<5 μg/L, fair—5–20 μg/L, and poor—>20 μg/L. For regionals scores Chlorophyll *a* concentrations were: good if less than 10 % of the coastal area was in poor condition, and more than 50 % of the coastal area was in good condition; fair if 10–20 % of the coastal area was in poor condition, or more than 50 % of the coastal area was in combined poor and fair condition; and poor if more than 20 % of the coastal area was in poor condition
Water clarity	Water clarity was estimated using specialized equipment that compared the amount and type of light reaching the water surface to the light at a depth of 1 m, as well as by using a Secchi disk. The water clarity indicator (WCI) was based on a ratio of observed clarity to reference conditions: WCI $=$ (observed clarity at 1 m)/(reference clarity at 1 m). The reference conditions were determined by examining available data for the region. In the Gulf Coast conditions were set at 10 % of incident light available at a depth of 1 m for normally turbid locations, 5 % for naturally highly turbid conditions, and 20 % for regions with significant Submerged Aquatic Vegetation beds or active restoration programs. For individual sampling sites the WCI ratio is good if it is >2, fair if it is between 1 and 2, and poor if it is <1. For regional scores water clarity was: good if less than 10 % of the coastal area was in poor condition, and more than 50 % of the coastal area was in good condition; fair if 10 % to 25 % of the coastal area was in poor condition, or more than 50 % of the coastal area was in combined poor and fair condition; and poor if more than 25 % of the coastal area was in poor condition
Dissolved oxygen	Dissolved oxygen was measured as part of the survey. For individual sampling sites Dissolved oxygen was rated Good—>5 mg/L, Fair—2–5 mg/L and Poor—$<$ 2 mg/L. For regional scores Dissolved oxygen concentrations were: good if less than 5 % of the coastal area was in poor condition, and more than 50 % of the coastal area was in good condition; fair if 5–15 % of the coastal area was in poor condition, or more than 50 % of the coastal area was in combined poor and fair condition; and poor if more than 15 % of the coastal area was in poor condition
Assessment and advisory data	Assessment and advisory data provided by states or other regulatory agencies was the third set of data used in this report to assess coastal condition. Several USEPA programs, including the Clean Water Act Section 305(b) Assessment Program, the National Listing of Fish and Wildlife Advisories (NLFWA) Program, and the Beaches Environmental Assessment, Closure, and Health (BEACH) Program, maintain databases that are repositories for information about how well coastal waters support their designated or desired uses. These uses are important factors in public perception of the condition of the coast and also address the condition of the coast as it relates to public health. The data for these programs were collected from multiple state agencies and data collection and reporting methods differed among states. Because of these inconsistencies, data generated by these programs are not included in the estimates of coastal condition
Designated or desired uses	Clean Water Act Section 305(b) Assessments and Beach Advisories and Closures data were utilized the same as in NCCR I (USEPA 2001)

(*continued*)

Table A.1 (continued)

Information	Details
National Estuary Program Coastal Condition Report (USEPA 2006)	
Data sources	The objective of this National Estuary Program Coastal Condition Report (NEP CCR) was to report on the condition of the nation's 28 NEP estuaries. The NEP CCR presented two major types of monitoring data for each NEP estuary: (1) data collected as part of USEPA's National Coastal Assessment (NCA) and (2) data collected by the individual NEPs or by the NEPs in partnership with interested stakeholders, including state environmental agencies, universities, or volunteer monitoring groups. Together, these data painted a picture of the overall condition of the coastal resources of the nation's NEP estuaries In addition to the NCA-based assessments, this report provided individual profiles of the 28 NEP estuaries that describe the indicators each NEP uses to address specific environmental concerns, including water and sediment quality, habitat quality, living resources, and environmental stressors, as appropriate. Each profile includes background information on the NEP estuary discussed, maps of the NEP study area, and data on the population pressures that affect the study area, including the total population (2000), population density (2000), and population growth rate (1960–2000) in NOAA-designated coastal counties that are within or transect the boundaries of the study area (Full Report at http://water.epa.gov/type/oceb/nep/upload/2007_05_09_oceans_nepccr_pdf_large_section1.pdf, accessed June 21, 2015)
Methodology	All of the methodologies, assessments, and ratings procedures for this report were the same as for NCCRII (USEPA 2004). The ratings in this report were based solely on NCA monitoring data and not the data collected by the individual NEPs. The NCA data were collected from 1997 through 2003 for four primary indices of estuarine condition (water quality index, sediment quality index, benthic index, and fish tissue contaminants index)
Effects of nutrient enrichment in the nation's estuaries: A decade of change (Bricker et al. 2007)	
Data sources	The evaluation included national data sets such as physical and hydrologic characteristics and nutrient loading
Methodology	This assessment evaluated the factors that influence water quality. Influencing factors that link a system's natural sensitivity to eutrophication and the nutrient loading and eutrophic symptoms actually observed illustrating the relationship between eutrophic conditions and use impairments. A system's eutrophic condition was assessed based on five water quality variables related to nutrient enrichment (chlorophyll *a*, macroalgal blooms, dissolved oxygen, loss of submerged vegetation and nuisance/toxic blooms) The data set included concentration or occurrence of problem conditions, and also characteristics such as duration, spatial coverage, frequency of occurrence of observed conditions, and data confidence. An increase in two of the primary symptoms indicates the first stage of water quality degradation associated with eutrophication. Epiphytes were omitted from this assessment due to the lack of a standard measure and data availability. Secondary symptoms are: low dissolved oxygen levels, loss of submerged aquatic vegetation, and occurrences of nuisance/toxic algal blooms. Nutrient concentrations were not used because they reflect the net biological, physical, and chemical processes such that even a severely degraded water body may exhibit low concentrations due to uptake by phytoplankton and macroalgae. Conversely, a relatively healthy system

(*continued*)

Table A.1 (continued)

Information	Details
	might have high nutrient concentrations due to low algal uptake as a result of light-limiting turbid waters, or may simply flush nutrients so quickly that phytoplankton do not have the opportunity to bloom extensively. For these reasons, nutrient concentrations may not be accurate indicators. In many estuaries, primary symptoms lead to more serious secondary symptoms, including low dissolved oxygen, loss of submerged aquatic vegetation (SAV), and nuisance/toxic blooms. In some cases, secondary symptoms can exist in the estuary without originating from primary symptoms. Such systems were consequently given a lower rating for nuisance/toxic blooms. Low ratings were also used because it is unclear whether offshore nuisance/toxic algal blooms grow and are maintained as a result of land-based nutrient sources (an increasing problem, regardless of bloom origin)
National Coastal Condition Report (NCCR III) (USEPA 2008)	
Data sources	NCCR III is based primarily on USEPA's National Coastal Assessment (NCA) data collected in 2001 and 2002. The NCA; NOAA's National Marine Fisheries Service (NMFS) and National Ocean Service; USFWS's National Wetlands Inventory (NWI); and USGS contributed most of the information presented in the report. Three types of data were presented in this report: Coastal Monitoring Data—Coastal monitoring data were obtained from programs such as USEPA's Environmental Monitoring and Assessment Program (EMAP) and NCA, NOAA's National Status & Trends (NS&T) Program, and FWS's NWI; Offshore Fisheries Data—These data are obtained from programs such as NOAA's Marine Monitoring and Assessment Program and Southeast Area Monitoring and Assessment Program. These data are used in this report to assess the condition of coastal fisheries in large marine ecosystems (LMEs); and Assessment and Advisory Data—These data are provided by states or other regulatory agencies and compiled in nationally maintained databases. These data provide information about designated-use support, which affects public perception of coastal condition as it relates to public health. The agencies contributing these data use different methodologies and criteria for assessment; therefore, the data cannot be used to make broad-based comparisons among the different coastal areas
Methodology	The data are used to rate indices and component indicators of coastal condition. The index scores are then used to calculate overall condition scores and ratings for the regions and the nation. The rating criteria for each index and component indicator in each region were determined based on existing criteria, guidelines, interviews with USEPA decision makers and other resource experts, and/or the interpretation of scientific literature. All of the methodologies, assessments, and ratings procedures for this report were the same as for NCCRII (USEPA 2004)
National Coastal Condition Report (NCCR IV) (USEPA 2012)	
Data sources	NCCR IV is based primarily on USEPA's NCA data collected between 2003 and 2006. The NCA, the NOAA's NMFS and NOS, and the USFWS's NWI contributed most of the information presented in this current report
Methodology	The data are used to rate indices and component indicators of coastal condition. The index scores are then used to calculate overall condition scores and ratings for the regions and the nation. The rating criteria for each index and component indicator in each region were determined based on existing criteria, guidelines, interviews with USEPA decision makers and other resource experts, and/or the interpretation of scientific literature. All of the methodologies, assessments, and ratings procedures for this report were the same as for NCCRIII (USEPA 2004)

APPENDIX B

Table B.1. Characteristics of Common Organic Contaminants in Marine Waters, Including Sources, Toxicity, and Fate in the Environment (modified from Kimbrough et al. 2008 and references therein)

Sources	Toxicity	Fate
Chlordanes: a group of organic pesticides called cyclodienes. It is a technical mixture whose principal components are alpha-chlordane, gamma-chlordane, heptachlor, and nonachlor)		
Chlordane, an insecticide, is a complex mixture of at least 50 compounds. It was used in the United States from 1948–1983 for agricultural and urban settings to control insect pests. It was also the predominant insecticide for the control of subterranean termites. Agricultural uses were banned in 1983, and all uses were banned by 1988	Exposure to chlordane can occur through eating crops from contaminated soil, fish and shellfish from contaminated waters, or breathing contaminated air. Chlordane can enter the body by being absorbed through the skin, inhalation, and ingestion. At high levels, chlordane can affect the nervous system, digestive system, brain, and liver, and is also carcinogenic. Chlordane is highly toxic to invertebrates and fish	Removal from both soil and water sources is primarily by volatilization and particle-bound runoff. In air, chlordane degrades as a result of photolysis and oxidation. Chlordane exists in the atmosphere primarily in the vapor-phase, but the particle-bound fraction is important for long-range transport. Chlordane binds to dissolved organic matter, further facilitating its transport in natural waters
DDT (dichlorodiphenyltrichloroethane)		
DDT was used worldwide as an insecticide for agricultural pests and mosquito control. Its use in the United States was banned in 1972, but it is still used in some countries today	Due to its environmental persistence and hydrophobic nature, DDT bioaccumulates in organisms. Many aquatic and terrestrial organisms are highly sensitive to DDT. As a result of DDT's toxic effect on wildlife, in particular birds, its usage was banned in the United States	DDT transforms to DDD and DDE, the latter being the predominant form found in the environment. Evaporation of DDT from soil followed by long distance transport results in its widespread global distribution. DDT and its transformation products are persistent and accumulate in the environment because they resist biodegradation. DDT that enters surface waters is subject to volatilization, adsorption to suspended particulates and sediment, and bioaccumulation. About half of the atmospheric DDT is adsorbed to particulates
Dieldrins		
Dieldrin is defined as the sum of two compounds, dieldrin and aldrin. Dieldrin and a related compound (aldrin) were widely used as insecticides in the 1960s for the control of termites around buildings and general crop protection from insects. In 1970, all uses of aldrin and dieldrin were canceled based on concern that	Exposure to aldrin and dieldrin occurs through ingestion of contaminated water and food products, including fish and shellfish, and through inhalation of indoor air in buildings treated with these insecticides. Aldrin is rapidly metabolized to dieldrin in the human body. Acute and long-term human exposures are associated	Aldrin is readily converted to dieldrin, while dieldrin is resistant to transformation. Dieldrin bioaccumulates and is magnified through aquatic food chains and has been detected in tissue of freshwater and saltwater fish, and marine mammals. Aldrin and dieldrin applied to soil are tightly bound, but may be transported to

(*continued*)

Table B.1 (continued)

Sources	Toxicity	Fate
they could cause severe aquatic environmental change and their potential as carcinogens. The cancellation was lifted in 1972 to allow limited use of aldrin and dieldrin, primarily for termite control. All uses of aldrin and dieldrin were again cancelled in 1989	with central nervous system intoxication. Aldrin and dieldrin are carcinogenic to animals and classified as likely human carcinogens	streams and rivers by soil erosion. Volatilization is the primary loss mechanism from soil. Dieldrin undergoes minor degradation to photodieldrin in marine environments
Polycyclic aromatic hydrocarbons (PAHs)		
Polycyclic aromatic hydrocarbons (PAHs) are found in creosote, soot, petroleum, coal, and tar. PAH can also have natural sources (e.g., forest fires, volcanoes) in addition to anthropogenic sources (automobiles emissions, home heating, coal-fired power plants). PAHs are formed from the fusing of benzene rings during the incomplete combustion of organic materials. They are also found in oil and coal. The main sources of PAHs to the environment are forest fires, coal-fired power plants, and automobile exhaust and local releases of oil	Made up of a suite of hundreds of compounds, PAHs exhibit a wide range of toxicities. Human exposure to PAHs can come as a result of being exposed to smoke from forest fires, automobile exhaust, home heating using wood, grilling and cigarettes. Toxic responses to PAHs in aquatic organisms include reproduction inhibition, mutations, liver abnormalities and mortality. Exposure to aquatic organisms can come as a result of oil spills, boat exhaust and urban runoff	The fate and transport of PAHs is variable and dependent on the physical properties of each individual compound. Most PAHs strongly associate with particles; larger PAH compounds (high molecular weight) associate to a higher degree with particles relative to smaller PAH compounds (low molecular weight). Smaller compounds predominate in petroleum products whereas larger compounds are associated with combustion
Polychlorinated biphenyl: there are 209 possible PCB (polychlorinated biphenyl) compounds, called “congeners” that were marketed as mixtures known as Aroclor)		
PCBs are synthetic organic chemicals composed of biphenyl substituted with varying numbers of chlorine atoms. They were manufactured between 1929 and 1977. PCB use was regulated in 1971, and new uses were banned in 1976. PCBs were used in electrical transformers, capacitors, lubricants and hydraulic fluids. Other uses included paints, adhesives, plasticizers and flame retardants. Manufacturing of PCBs for use as flame retardants and lubricants stopped in 1977. Currently, PCBs are predominately used in electrical applications and can still be found in transformers and electrical equipment	The main human exposure route for PCBs is through eating contaminated seafood and meats. PCBs are associated with skin ailments, neurological and immunological responses and at high doses can decrease motor skills and cause liver damage, and memory loss. Exposure of aquatic life to PCBs results in birth defects, lowered fecundity, cancer and death. PCBs are hazardous because they are toxic, degrade slowly and bioaccumulate	PCBs are persistent in the environment and associate with particles in aquatic systems as a result of their strong hydrophobic nature. They are long lived in the environment; improper disposal and leakage is responsible for environmental introduction

APPENDIX C

Table C.1. Characteristics of Common Metal Contaminants Including Origins, Toxicity, and Fate in the Environment (modified from Kimbrough et al. 2008 and references therein)

Contaminant	Origins	Toxicity	Fate
Arsenic (As)	Arsenic has natural and industrial sources. Products that contain arsenic include: preserved wood, semiconductors, pesticides, defoliants, pigments, antifouling paints, and veterinary medicines. In the recent past, as much as 90 % of arsenic was used for wood preservation. Atmospheric sources of arsenic include smelting, fossil fuel combustion, power generation, and pesticide application	Arsenic is toxic at high concentrations to fish, birds and plants. In animals and humans prolonged chronic exposure is linked to cancer. Inorganic arsenic, the most toxic form, represents approximately 10 % of total arsenic in bivalves. Less harmful organic forms, such as arsenobetaine, predominate in seafood.	Human activities have changed the natural biogeochemical cycle of arsenic leading to contamination of land, water and air. Arsenic in coastal and estuarine water occurs primarily from river runoff and atmospheric deposition. The major source of elevated levels of arsenic in the nation is natural crustal rock
Cadmium (Cd)	Cadmium occurs naturally in the earth's crust as complex oxides and sulfides in ores. Products that contain cadmium include batteries, color pigment, plastics and phosphate fertilizers. Industrial sources and uses include zinc, lead and copper production; electroplating and galvanizing; smelting; mining; fossil fuel burning; waste slag; and sewage sludge. Anthropogenic emissions, originate from a large number of diffuse sources	Cadmium is toxic to fish, salmonoid species and juveniles are especially sensitive, and chronic exposure can result in reduction of growth. Respiration and food represent the two major exposure pathways for humans to cadmium	Cadmium has both natural and non-point anthropogenic sources. Natural sources include river runoff from cadmium rich soils, leaching from bedrock, and upwelling from marine sediment deposits. Cadmium is transported by atmospheric processes as a result of fossil fuel burning, erosion, and biological activities. Land-based runoff and ocean upwelling are the main conveyors of cadmium into coastal environments. Elevated cadmium levels are primarily located in freshwater-dominated estuaries consistent with river transport of cadmium to coastal environments

(*continued*)

Table C.1 (continued)

Contaminant	Origins	Toxicity	Fate
Copper (Cu)	Copper is a naturally occurring ubiquitous element in the environment. Trace amounts of copper are an essential nutrient for plants and animals. Anthropogenic sources include mining, manufacturing, agriculture, sewage sludge, antifouling paint, fungicides, wood preservatives, and vehicle brake pads. The United States ranks third in the world for utilization and second in production. The USEPA phase-out of chromated copper arsenate (CCA) wood preservatives and the 1980s restrictions on tributyltin marine antifouling paint has stimulated a transition to copper-based wood preservatives and marine antifouling paint	Copper can be toxic to aquatic organisms; juvenile fishes and invertebrates are much more sensitive to copper than adults. Although copper is not highly toxic to humans, chronic effects of copper occur as a result of prolonged exposure to large doses and can cause damage to the digestive tract and eye irritation	The most common form of copper in water is Cu (II), it is mostly found bound to organic matter. Transport of copper to coastal and estuarine water occurs as a result of runoff and river transport. Atmospheric transport and deposition of particulate copper into surface waters may also be a significant source of copper to coastal waters
Lead (Pb)	Lead is a ubiquitous metal that occurs naturally in the earth's crust. Environmental levels of lead increased worldwide over the past century because of leaded gasoline use. Significant reductions in source and load resulted from regulation of lead in gasoline and lead based paints. High levels found in the environment are usually linked to anthropogenic activities such as manufacturing processes, paint and pigment, solder, ammunition, plumbing, incineration, and fossil fuel burning. In the communications	Lead has no biological use and is toxic to many organisms, including humans. Exposure of fish to elevated concentrations of lead results in neurological deformities and black fins in fish. Lead primarily affects the nervous system, which results in decreased mental performance and mental retardation in humans. Exposure to lead may also cause brain and kidney damage, and cancer	Loadings of lead into coastal waters are primarily linked with wastewater discharge, river runoff, atmospheric deposition, and natural weathering of rock. Lead can be found in air, soil, and surface water

(*continued*)

Table C.1 (continued)

Contaminant	Origins	Toxicity	Fate
	industry, lead is still used extensively as protective sheathing for underground and underwater cables, including transoceanic cable systems		
Mercury (Hg)	Mercury is a highly toxic, nonessential trace metal that occurs naturally. Elevated levels occur as a result of human activity. In the United States, coal-fired electric turbines, municipal and medical waste incinerators, mining, landfills, and sewage sludge are the primary emitters of mercury into the air	Mercury is a human neurotoxin that also affects the kidneys and developing fetuses. The most common human exposure route for mercury is the consumption of contaminated food. Children, pregnant women or women likely to become pregnant are advised to avoid consumption of swordfish, shark, king mackerel and tilefish and should limit consumption to fish and shellfish recommended by FDA and USEPA	In the environment, mercury may change forms between elemental, inorganic and organic. Natural sinks, such as sediment and soil, represent the largest source of mercury to the environment. Estimates suggest that wet and dry deposition accounts for 50–90 % of the mercury load to many estuaries, making atmospheric transport a significant source of mercury worldwide. Long-range atmospheric transport is responsible for the presence of mercury at or above background levels in surface waters in remote areas
Nickel (Ni)	Nickel is a naturally occurring, biologically essential trace element that is widely distributed in the environment. It exists in its alloy form and as a soluble element. Nickel is found in stainless steel, nickel-cadmium batteries, pigments, computers, wire, and coinage and is used for electroplating	Food is the major source of human exposure to nickel. Exposure to large doses of nickel can cause serious health effects, such as bronchitis, while long-term exposure can result in cancer. There is no evidence that nickel biomagnifies in the food chain	Nickel derived from weathering rocks and soil is transported to streams and rivers by runoff. It accumulates in sediment and becomes inert when it is incorporated into minerals. River and stream input of nickel are the largest sources for oceans and coastal waters. Atmospheric sources are usually not significant
Tin (Sn)	Tin sources in coastal water and soil include manufacturing and processing facilities. It also occurs in trace amounts in natural waters. Concentrations	Humans are exposed to elevated levels of tin by eating from tin-lined cans and by consuming contaminated seafood. Exposure to elevated levels of tin compounds	Tin enters coastal waters bound to particulates, and from riverine sources derived from soil and sediment erosion. Bio concentration factors for inorganic tin were

(*continued*)

Table C.1 (continued)

Contaminant	Origins	Toxicity	Fate
	in unpolluted waters and the atmosphere are often near analytical detection limits. Tin has not been mined in the United States since 1993	by humans leads to liver damage, kidney damage, and cancer	reported to be 1,900 and 3,000 for marine algae and fish. Inorganic tin can be transformed into organometallic forms by microbial methylation and is correlated with increasing organic content in sediment. Tin is regarded as being relatively immobile in the environment and is rarely detected in the atmosphere. It is mainly found in the atmosphere near industrial sources as particulates from combustion of fossil fuels and solid waste
Zinc (Zn)	As the fourth most widely used metal, zinc's anthropogenic sources far exceed its natural ones. The major industrial sources include electroplating, smelting and drainage from mining operations. The greatest use of zinc is as an anticorrosive coating for iron and steel products (sheet and strip steel, tube and pipe, and wire and wire rope). Canada is one of the largest producers and exporters of zinc. The United States is the largest customer for Canadian refined zinc, and the automobile industry is the largest user of galvanized steel	Zinc is an essential nutrient. Human exposure to high doses of zinc may cause anemia or damage to the pancreas and kidneys. However, zinc does not bioaccumulate in humans; therefore, toxic effects are uncommon and associated with excessively high doses. Fish exposed to low zinc concentrations can sequester it in some cases	Dissolved zinc occurs as the free hydrated ion and as dissolved complexes. Changes in water conditions (pH, redox potential, chemical speciation) can result in dissolution from or sorption to particles. In air, zinc is primarily found in the oxidized form bound to particles. Zinc precipitates as zinc sulfide in anaerobic or reducing environments, such as wetlands, and thus is less mobile, while remaining as the free ion at lower pHs. As a result of natural and anthropogenic activities, zinc is found in all environmental compartments (air, water, soil, and biota)
Butyltins	Tributyltin is used as an antifouling agent in marine paints applied to boat hulls. Slow release from the paint into the aquatic system retards organism attachment and increases ambient	Tributyltin is an extremely toxic biocide that is regulated as a result of its toxic effects (reproduction and endocrine disruption) on nontarget aquatic species. Organotin	Tributyltin is sparingly soluble in water and associates readily with suspended particles in the water column. Butyltins are persistent in the aquatic environment and accumulate in

(*continued*)

Table C.1 (continued)

Contaminant	Origins	Toxicity	Fate
	environmental levels. The United States partially banned the use of tributyltin in 1988 for use on boats less than 25 m in length, drastically limiting use on many recreational vessels	compounds are readily bio-accumulated by aquatic organisms from water but there is no evidence for biomagnification up the food chain. Sex changes have been shown to occur in gastropods exposed to elevated levels of tributyltin	sediment; therefore, they will continue to be a source of butyltin to the aquatic environment. Tributyltin transforms to dibutyltin and then to monobutyltin. Releases of organotins to the atmosphere are not significant due to their low vapor pressure and rapid photodegradation

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http://www.springer.com/978-1-4939-3445-4

Habitats and Biota of the Gulf of Mexico: Before the Deepwater Horizon Oil Spill
Volume 1: Water Quality, Sediments, Sediment Contaminants, Oil and Gas Seeps, Coastal Habitats, Offshore Plankton and Benthos, and Shellfish
Ward, C.H. (Ed.)
2017, LIX, 868 p. 551 illus., 519 illus. in color., Hardcover
ISBN: 978-1-4939-3445-4