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Annual Review

ECOLOGICAL CONDITION OF THE ESTUARIES OF THE ATLANTIC AND GULF COASTS OF THE UNITED STATES

23148

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Abstract—Monitoring the estuaries of the Atlantic and Gulf of Mexico coastlines of the United States from Cape Cod, Massachusetts, to Brownsville, Texas, was performed annually from 1990 through 1997 to assess ecological conditions on a regional basis for four biogeographic provinces. These province estimates—Virginian, Carolinian, West Indian, and Louisianian Provinces—are combined to provide an assessment of 87% of the estuarine area of the United States and 96% of the area of the Atlantic and Gulf coasts. Combining information over the six years of monitoring showed 34 ± 4% of the Atlantic and Gulf estuarine sediments displayed poorer than expected biological conditions, based on benthic and finfish community conditions, and 21 ± 4% of the area was characterized by low water clarity, the presence of marine debris/noxious odors, or elevated fish tissue contaminants.

Keywords—Estuaries Coastal ecosystems Coastal 2000 Environmental monitoring program

INTRODUCTION

Estuaries are bodies of water that are balanced by freshwater and sediment influx from rivers and the tidal actions of the oceans, thus providing transition zones between the fresh water of a river and the saline environment of the sea. The result of this interaction is an environment where estuaries, along with their adjacent marshes and seagrasses, provide a highly productive ecosystem that supports wildlife and fisheries and contributes substantially to the economy of coastal areas.

Coastal areas are the most developed in the United States. The narrow fringe (comprising 17% of the nation's land mass) is home to more than 53% of the nation's population [1]. This pattern in coastal populations is increasing by 3,600 people per day, resulting in a projected population increase of 27 million in the next decade [http://state_of_the_coast.noaa.gov/bulletins/html/pop_01.html]. In addition to being centers for populations, U.S. coasts are a source of valuable commodities—31% of the gross national product and 85% of commercially harvested fish depend on estuarine habitats; 180 million people use coastal resources annually for swimming, diving, and boating; and estuaries receive discharges from municipalities and industries [2,3]. Approximately $15 billion in public funds are spent annually on outdoor marine and estuarine recreation in the 18 coastal states bordering the Atlantic Ocean and the Gulf of Mexico [4].

Despite the importance of the coastal region to the nation's economy and well being, little is actually known about the status and trends of critical environmental variables in coastal regions. Other than coastal weather, water levels, and commercial fisheries, there are few consistent measurements of the ecological condition of estuaries. There is at present in the United States no nationally consistent, comprehensive monitoring program to provide the information necessary for effective management and decision making for coastal ecosystems. However, for the last decade, the U.S. Environmental Protection Agency Office of Research and Development has been developing monitoring approaches and indicators that could be used in a comprehensive monitoring program. The Environmental Monitoring and Assessment Program (EMAP) surveyed and assessed estuarine conditions in about 87% of the estuarine acreage in the continental United States between 1990 and 1997. The information is reported here and is being used to initiate the first synoptic national monitoring survey of estuarine resources in 2000 and 2001 (Coastal 2000). The 1990 through 1997 surveys conducted along the Atlantic and Gulf of Mexico coasts represents data available to develop a baseline of ecological conditions.

METHODS

Regional surveys were conducted in the Virginian (1990–1993), Carolinian (1995–1997), West Indian (1995–1996), and Louisianian (1991–1994) Provinces (Fig. 1), sampling 100 to 150 sites annually in each province. Sites were selected from three different strata using a probability-based design [5]. A simple classification system based on physical dimensions was used to delineate the three sampling strata—large estuaries (>250 km^2, length/mean width or aspect < 18), large tidal rivers (>250 km^2, aspect > 18), and small estuarine systems (2–250 km^2). Along the Atlantic and Gulf of Mexico coastlines, 1,516 estuaries totaling 74,744 km^2 were identified that met the above criteria—42 large estuaries (43,536 km^2), 1,464 small estuaries or small tidal rivers (27,259 km^2), and the tidal portions of 10 large tidal rivers (3,949 km^2). Table 1 lists the number of sites sampled for each of the years that sampling occurred in a province. All sites were sampled during a six- to eight-week index period in late summer (July 15–September 15). This time period was selected for sampling because it represents the time period most likely to show ecological effects due to decreased dissolved oxygen conditions, increased contaminant availability, and increased human usage.

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Fig. 1. Biogeographic provinces along the Atlantic and Gulf of Mexico coastlines that were sampled by Environmental Monitoring and Assessment Program-Coastal from 1990 through 1996.

Sites were characterized using selected indicators (Table 2) in order to determine the status of components of ecological condition. The strategy for the selection of indicators for use in EMAP-Coastal is described in detail in Knapp et al. [6], Griffith et al. [7], and Jackson et al. [http://www.epa.gov/emap/html/pubs/resdocs/]. Monitoring focused on indicators of ecological response to stress and used measures of exposure to stress as a means of interpreting that response. Indicators were added in some regions where the addition addressed a particular regional issue.

At each site, a set of samples and data was taken using standardized methods. Triplicate benthic samples were taken using a Young-modified Van Veen grab (440 cm^2) in order to provide data on the structure and composition of the benthic macroinvertebrate community. A small core (60 cm^3) was extracted from each grab sample for sediment characterization (percent silt-clay, grain size, and total organic carbon). Sediment samples for acid volatile sulfide determinations were collected from mid-Atlantic and Gulf of Mexico sites. The remainder of each grab was sieved through a 0.5-mm screen. Samples were preserved in 10% buffered rose-bengal formalin solution and stored at least 30 d prior to processing to assure adequate fixation [8]. After 30 d, the stored samples were transferred from formalin to ethanol, sorted, identified to species, and counted.

Additional sediment grabs were collected at each sampling site for sediment contaminant analyses and toxicity bioassays. Samples were collected from a homogenate created at the site from several (6–10) grabs from which the top 2 cm of sediment was removed, placed in a container, and thoroughly mixed until approximately 4 L of sediment had been obtained. This mixture was apportioned for sediment chemistry analyses and toxicity testing.

Analyses for the determination of sediment characteristics included grain size, percent silt-clay content, and total organic carbon at all sites. Grain size and silt-clay analyses were initially determined by sieving through a 63-μm mesh sieve. Both the filtrate and the fraction retained on the sieve were dried at 60°C and weighed to calculate the proportion of silts and clays. Grain size determination was determined by further fractionation of the sieve-retained portion through additional sieves prior to drying. Total organic carbon was determined by drying at least 5 g wet weight of sediment for 48 h, grinding to a fine consistency, acidifying to remove inorganic carbon (e.g., shell fragments), igniting at 950°C, and measuring the carbon dioxide evolved using an infrared gas analyzer.

Sediment samples for contaminant analyses were collected from the field homogenate at each site. The sediments were analyzed by standard methods [9] for the group of contaminants listed in Table 3. Most of the sediment from the homogenate was used for sediment bioassays. Toxicity tests were performed using the standard 10-d test method [10,11] with *Ampelisca abdita*, the tube-dwelling amphipod. Five replicate tests were completed under static conditions for the listed time length at 20°C and 30 ppt.

Fish, shrimp, and blue crabs were collected by trawling (depending on location) with a 16-ft high-rise otter trawl with a 2.5-cm mesh cod end in the Carolinian and Louisianian Provinces, with fish traps in the West Indian Province due to trawling restrictions in Everglades National Park (FL, USA), and with a 15-m high-rise otter trawl with a 2.5-cm mesh cod end in the deeper waters of the Virginian Province. The net was towed for 10 min against the current at a speed of between 0.7 and 1.0 m/s. All fish and shellfish caught in the trawls and traps were identified to species and counted and up to 20 to 30 individuals of each species were measured to the nearest millimeter. All fish were examined for external pathologies. This inspection included body spinal alignment, lumps, bumps, bruises, growths, opercular deformity, fin erosion, eye deformities, buccal cavity growths and hemorrhages, parasitism, and overall body form.

Up to 10 target fish/shellfish (species depending on geographic location; Table 4) were retained for tissue residue analysis. The specimens were labeled, frozen, and shipped to the appropriate laboratory, where they were stored frozen until analysis. Where available, 4 to 10 individuals of each species from each sampling site were analyzed by compositing fillets into a homogeneous slurry. The edible portions of these fish and shellfish included fillets with skin for Atlantic croakers, white perch, and seatrout; fillets without skin for all catfish; tail meat for shrimp; and picked lump and claw meat for blue crabs. This slurry was appropriately digested, extracted, and

Table 1. Number of stations sampled from 1990 through 1996, by province

Province	Year							Total
	1990	1991	1992	1993	1994	1995	1996	
Virginian	181	102	104	103	0	0	0	425
Carolinian	0	0	0	0	84	86	44	214
West Indian	0	0	0	0	0	88	0	88
Louisianian	0	100	100	103	103	0	0	406
Total	181	202	204	206	187	174	44	1,133

Table 2. The ecological indicators used during the 1990 through 1996 EMAP-Coastal Monitoring Program

Indicator type	Indicator
Response	Benthic community composition
	Benthic abundance
	Fish community composition
	Pathologies in fish
	Presence of submerged aquatic vegetation
Exposure	Sediment contaminant concentrations
	Sediment toxicity
	Dissolved oxygen concentrations
	Contaminant concentrations in fish tissue
Habitat	Percent light transmittance
	Salinity
	Temperature
	pH
	Percent silt-clay
	Grain size

Table 3. List of organic and inorganic compounds determined in both sediment and tissue samples

Polynuclear aromatic hydrocarbons (PAHs)
Acenaphthene
Anthracene
Benz[*a*]anthracene
Benzo[*a*]pyrene
Biphenyl
Chrysene
Dibenz[*a,h*]anthracene
Dibenzothiophene
2,6-Dimethylnaphthalene
Fluoranthene
Fluorene
2-Methylnaphthalene
1-Methylnaphthalene
1-Methylphenanthrene
2,6-Dimethylnaphtalene
Naphthalene
Pyrene
Benzo[*b*]fluoranthene
Acenaphthylene
Benzo[*k*]fluoranthene
Benzo[*g,h,i*]perylene
Ideno[1,2,3-*c,d*]pyrene
2,3,5-Trimethylnaphthalene
PCB congeners
8 (2,4′-dichlorobiphenyl)
18 (2,2′,5-trichlorobiphenyl)
28 (2,4,4′-trichlorobiphenyl)
44 (2,2′,3,5′-tetrachlorobiphenyl)
52 (2,2′5,5′-tetrachlorobiphenyl)
66 (2,3′,4,4′-tetrachlorobiphenyl)
101 (2,2′,4,5,5′-pentachlorobiphenyl)
105 (2,3,3′,4,4′-pentachlorobiphenyl)
110/77 (2,3,3′,4′,6-pentachlorobiphenyl/ 3,3′,4,4′-tetrachlorobiphenyl)
118 (2,3,4,4′,5-pentachlorobiphenyl)
126 (3,3,4,4′,5-pentachlorobiphenyl)
128 (2,2′,3,3′,4,4′-hexachlorobiphenyl)
138 (2,2′,3,4,4′,5′-hexachlorobiphenyl)
153 (2,2′,4,4′,5,5′-hexachlorobiphenyl)
170 (2,2′,3,3′,4,4′,5-heptachlorobiphenyl)
180 (2,2′,3,4,4′,5,5′-heptachlorobiphenyl)
187 (2,2′,3,4′,5,5′,6-heptachlorobiphenyl)
195 (2,2′,3,3′,4,4′,5,6-octachlorobiphenyl)
206 (2,2′,3,3′,4,4′,5,5′,6-nonachlorobiphenyl)
209 (2,2′,3,3′,4,4′,5,5′,6,6′-decachlorobiphenyl)
DDT and its metabolites
2,4′-DDD
4,4′-DDD
2,4′-DDE
4,4′-DDE
2,4′-DDT
4,4′-DDT
Chlorinated pesticides other than DDT
Aldrin
Alpha-chlordane
Dieldrin
Endosulfan I
Endosulfan II
Endosulfan sulfate
Endrin
Heptachlor
Heptachlor epoxide
Hexachlorobenzene
Lindane (gamma-BHC)
Mirex
Toxaphene
Trans-nonachlor
Trace Elements
Aluminum
Antimony (sediment only)
Arsenic
Cadmium
Chromium
Copper
Iron
Lead
Manganese (sediment only)
Mercury
Nickel
Selenium
Silver
Tin
Zinc

analyzed according to the methods of the U.S. Environmental Protection Agency (U.S. EPA [12]).

Water quality information was collected at each site for instantaneous representations of temperature, salinity, pH, and dissolved oxygen. A Hydrolab Surveyor 2 (Hydrolab, Austin, TX, USA) equipped with a dissolved-oxygen electrode was used to make the instantaneous measurements between the hours of 9 AM and 4 PM. Vertical profiles of the water column at meter intervals from surface to bottom were taken at all sites. Proportion of surface light penetration was determined using a LICOR LI-1000 (LICOR, Lincoln, NB, USA) containing a submersible light sensor. Underwater readings at 1-m intervals were measured simultaneously with ambient surface light. The ratio of these two measures provides a measure of proportional light penetration based on incident light. The proportion reaching 1 m in depth was used as an indicator of water clarity.

Anthropogenically generated marine debris was determined from the contents of the benthic grabs, fish trawls, and surface floatables. The incidence and composition of this debris was determined for each site location.

DATA ANALYSIS

All ecological indicators collected from the Atlantic and Gulf coasts were characterized using cumulative distribution functions [13]. These functions describe the full distribution of these indicators in relation to their areal extent within the sampled province and are used primarily to determine the proportion of each province that is degraded with respect to that indicator. All observations were weighted by the inclusion probability assigned to each site location based on the surface area associated with each site, and this represents the probability of the sample's inclusion in the sampling design. For large estuaries in all provinces and all estuaries in the West Indian Province, the inclusion probability was equal to the hexagonal sampling space created by the design (280 km^2 in large estuaries of the Virginian, Louisianian, and Carolinian and 88 km^2 in all estuaries of the West Indian) divided by the total area of the large estuaries included in the province sampling or, in the case of the West Indian Province, all estuarine area sampled. For large tidal river and small tidal river/estuaries in the Virginian, Louisianian, and Carolinian Provinces, an alternate design and analytical approach was used. For large tidal rivers, the inclusion probability associated with each sampling segment was the surface area of the sampled segment divided by the area of the estuarine portion of the large river. This included resources like the Potomac River (VA), Indian River Lagoon (FL), Neuse River (NC), and Mississippi River (LA). For small estuaries and small tidal rivers in these provinces, the inclusion probability for any small tidal river/estuary was equal to the total surface area of that resource divided by

Table 4. Target species examined for residue analysis of edible tissue, by province

	Province			
Species	Virginian	Carolinian	West Indian	Louisianian
Catfish				
Ictalurus punctatus	X			
Ameiurus catus	X			
Bagre marinus			X	X
Arius felis			X	X
Atlantic croaker (*Micropogonias undulatus*)	X	X		X
Spot (*Leiostomus xanthurus*)		X		X
Shrimp				
Penaeus aztecus		X	X	X
Penaeus setiferus		X		
White perch (*Morone americana*)	X			
Weakfish (*Cynoscion regalis*)	X			
Bluefish (*Pomatomus saltatrix*)	X			
Winter flounder (*Pleuronectes americanus*)	X			

the sum of the surface areas of the small resources included in each year's survey. The approximate 95% confidence intervals for the province-level cumulative distribution functions were calculated based on Heimbuch et al. [14].

A benthic index in each of the biogeographic regions was created by combining multiple metrics into a single multimetric index of benthic condition for each province [15–19]. These indices integrate parameters of macrobenthic community structure and are capable of distinguishing polluted and unpolluted areas. While the indices are different in each province, their components are largely the same (e.g., community biodiversity, abundance of pollution-tolerant and pollution-sensitive species, proportional community composition), and each index represents a relative measure of the condition of benthic resources in that province.

Where appropriate, threshold values were used when assessing areas of degradation or when comparing biological indicators with stressors. Threshold limits for most water and sediment quality measurements were obtained from federal and state guidelines [20,21]. When official guidelines did not exist or could not be determined, the appropriate literature was examined and a consensus value determined. Guidelines used to assess potential for sediment degradation were the Long et al. [22] and Long and Morgan [23] median values (ER-M) associated with biological effects. In addition, the Long and Morgan [22] 10% values (ER-L) were used to assess locations where some contamination occurred at levels that had a low probability of resulting in biological effects. Threshold values for province-wide ecological condition were determined through combinations of the individual measures/indices and were based on an integration of literature values.

The proportion of estuarine area meeting acceptable human uses was determined by combining data representing tissue residues in target species, proportional light penetration, the presence/absence of marine debris, and the presence/absence of noxious odors from either the water column or sediments. Poor conditions (exceeding threshold values or presence in the case of odors and debris) of any of these measures were determined to constitute poor human use condition.

RESULTS

Overall condition

The overall health of Atlantic and Gulf coast estuaries is good based on data collected throughout the East and Gulf Coasts (based on nearly 1,000 stations sampled from 1990 through 1997). More specifically, about 56% of the estuaries are in good condition for supporting plants, animals, and human uses (Fig. 2). About 34% of the area of these estuarine resources has poor benthic and fish community conditions, while 33% has unacceptable levels for human-related uses.

Most of the biological communities in poor condition are benthic communities (bottom-dwelling organisms). These poor conditions occur in areas of hypoxia, eutrophication, sediment contamination, and habitat degradation. Depending on location along the Atlantic and Gulf Coasts' coastlines, poor benthic conditions ranged from 27 to 35% of estuarine sediments. Aquatic life is categorized as poor based on measures of biodiversity, increased abundances of pollution-tolerant species, and decreased abundances of pollution-sensitive species. Less than 1% of fish examined (~100,000 estuarine fish) throughout the United States showed evidence of fin erosion, skin lesions, eye disorders, or gill problems.

People use and enjoy estuarine resources in many ways, including swimming, boating, walking along the shore, and husbandry. Approximately 5 to 30% of the estuarine waters

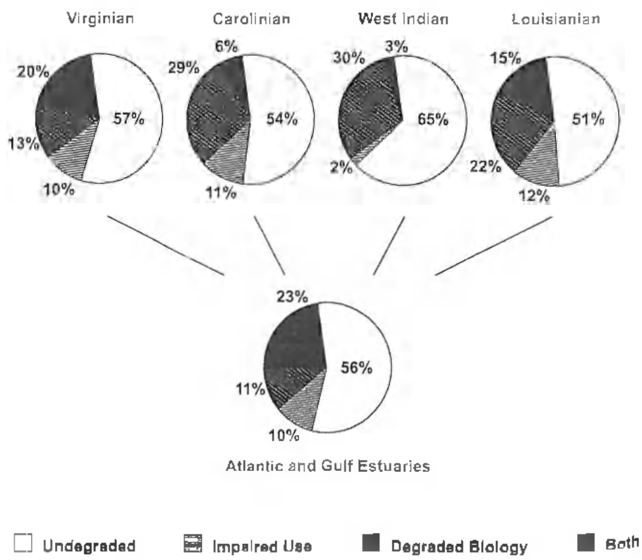

Fig. 2. Proportion of sampled estuarine area in each province that was assessed as having degraded biotic resources, having degraded human use, or being undegraded.

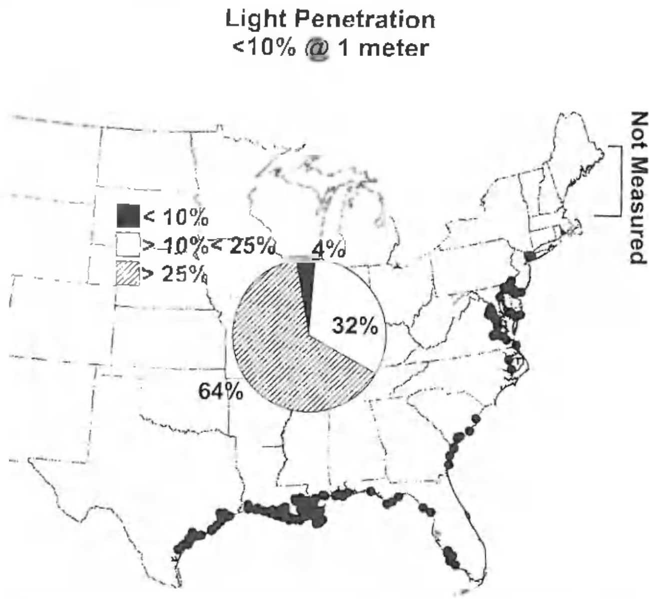

Fig. 3. The distribution and proportion of sampled area with light penetration at a depth of 1 m to be less than 10% of surface incident light.

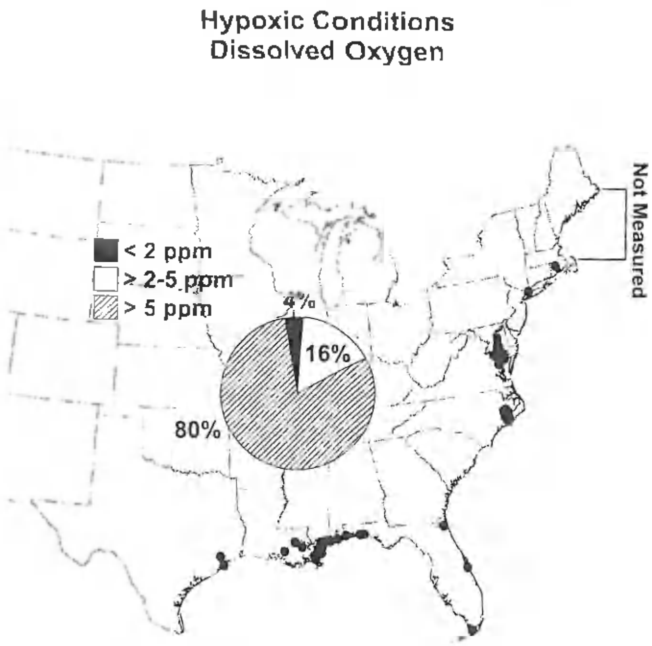

Fig. 4. The distribution and proportion of sampled area with dissolved oxygen concentrations of less than 2 ppm.

of the Atlantic and Gulf Coasts are categorized as degraded for some human use. There are three primary contributors to human use degradation, i.e., water clarity, which affects recreational activities; accumulation of marine debris and presence of noxious odors, which affects aesthetics and wildlife health; and bioaccumulation of contaminants in edible portions of fish and shellfish, which affect consumption.

Water quality

Eutrophic condition is based primarily on light penetration and dissolved oxygen conditions. Clear waters are valued by society and contribute to the maintenance of healthy and productive ecosystems. Losses of submerged aquatic vegetation can occur when light is decreased due to turbid water associated with overgrowth of algae. Water visibility of <10% at 1-m depth (10% of surface light reaches 1 m) is used to indicate poor conditions. This is equivalent to being unable to see your hand in front of your face at a depth of 1 m. Poor light penetration is a problem in 4% of estuarine waters, primarily in the western Gulf of Mexico and western tributaries of the Chesapeake Bay (Fig. 3).

Low dissolved oxygen often occurs as a result of large algal blooms that sink to the bottom and use oxygen during the process of decay. Dissolved oxygen is a fundamental requirement for all estuarine life. A threshold concentration of 4 to 5 ppm is used by many states to set water quality standards. A concentration of 2 ppm is thought to be extremely stressful to most estuarine organisms. Low levels of oxygen (hypoxia) or a lack of oxygen (anoxia) often result from the onset of increased bacterial degradation of organic materials (e.g., chlorophyll produced by an algal bloom), sometimes resulting in algal scums, fish kills, and noxious odors as well as habitat loss and degraded aesthetic values. This results in a loss of tourism and recreational water use. The EMAP estimates that 4% of estuarine bottom waters are hypoxic (<2 ppm) while about 80% of waters maintain high levels of dissolved oxygen (>5 ppm) (Fig. 4).

Sediment quality

Measurements of over 100 contaminants, including over 25 polynuclear aromatic hydrocarbons, 22 polycyclic biphenyl congeners (PCBs), total PCBs, over 25 pesticides, and 15 metals, have been taken at each site. One to two percent of estuarine sediments in the United States show concentrations of contaminants (polycyclic aromatic hydrocarbons, PCBs, pesticides, and metals) that are above ER-M guidelines (the concentration of a contaminant associated with adverse effects on estuarine organisms in the field and laboratory) while 10 to 29% of sediments have contaminant concentrations that exceed the ER-L guidelines (concentration having a low probability of affecting organisms adversely) (Fig. 5). Most of the loca-

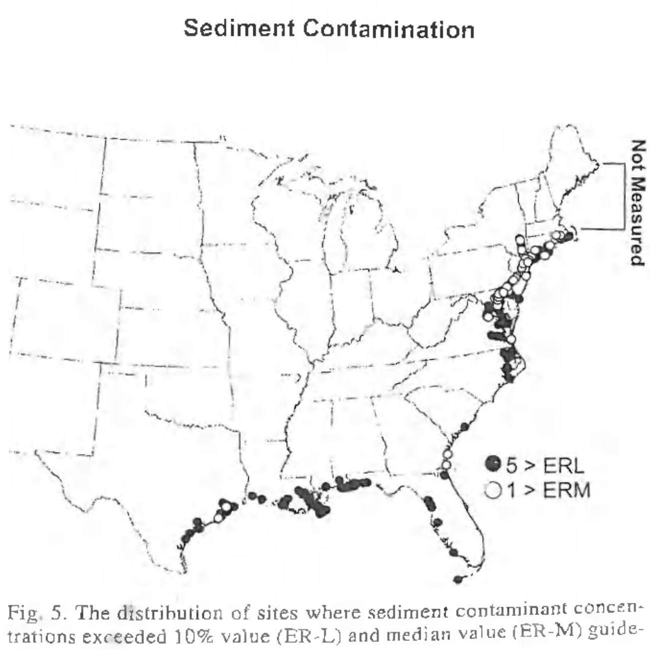

Fig. 5. The distribution of sites where sediment contaminant concentrations exceeded 10% value (ER-L) and median value (ER-M) guidelines [22,23].

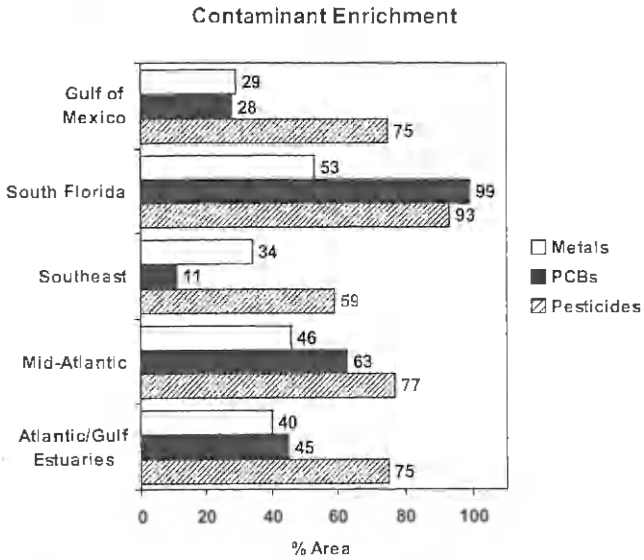

Fig. 6. The proportion of estuarine sediments that are enriched by anthropogenic sources.

tions exceeding the ER-M guidelines are located in the mid-Atlantic while the Gulf of Mexico coast contains many locations with exceedances of the ER-L for five or more contaminants.

One of the challenges of assessing the magnitude of sediment contamination is differentiating contaminants (organics, metals, and pesticides) that may occur naturally in the earth's crust from those that are added from human activities. The PCBs are relatively easy to evaluate since they can only come from human activities. Similarly, with the exception of arsenical, cyanide, microbial, and botanical pesticides, most pesticides also come from human activities. However, polynuclear aromatic hydrocarbons, the above listed pesticides, and metals can and do naturally occur in estuarine sediments. The enrichment of sediments due to human sources is shown in Figure 6. These measurements show that 40, 45, and 75% of estuarine sediments are enriched with metals, PCBs, and pesticides, respectively, from human sources.

Chemical analyses of sediments can provide information on the concentrations and mixtures of potentially toxic substances in sediment samples. However, information gained from these analyses alone provides no direct measure of the toxicological significance of the chemicals. The Atlantic and Gulf Coastal Status and Trends Program and EMAP have been conducting surveys of sediment toxicity throughout the United States since 1981. Over 1,000 locations have been tested using *Ampelisca abdita*, an amphipod the naturally occurs in estuarine sediments. The EMAP test results show that 10% of sediments in the estuaries of the United States are toxic (resulting in significant mortalities) to amphipods exposed to sediments for 10 d (Fig. 7).

Mortality is not the only effect that contaminated sediments can have on benthic organisms. Sublethal effects, including reductions in growth, changes in community structure (biodiversity), and changes in abundance (reproduction), can occur as a result of exposure to contaminated sediments. The EMAP benthic indices reflect changes in benthic community diversity and the abundances and ratios of pollution-tolerant and pollution-sensitive species. Twenty-two percent of estuarine sediments are characterized by benthic communities that are less diverse than expected, are populated by greater than the expected number of pollution-tolerant species, and contain fewer than expected pollution-sensitive species (Fig. 8). These differences appear to result large from contaminated sediments, hypoxic conditions, habitat degradation, and eutrophication.

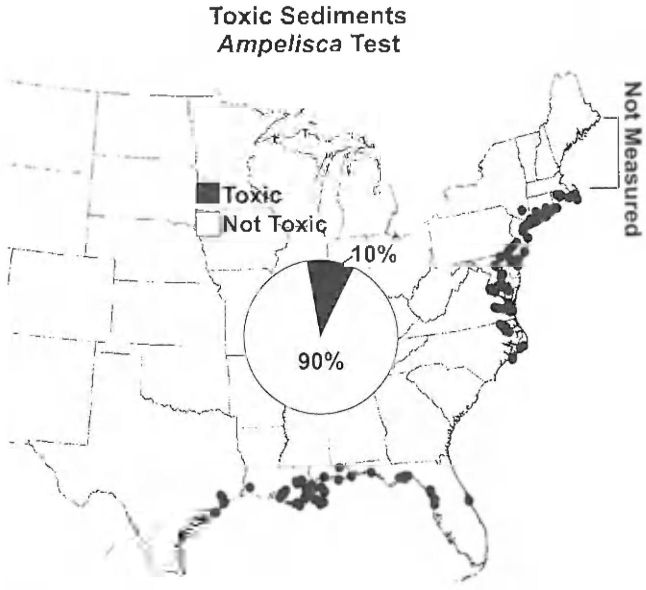

Fig. 7. The distribution and proportion of estuarine sediments that were toxic in *Ampelisca abdita* bioassays (control-corrected mortality > 15%).

Biotic condition

Estuarine biota are negatively affected in about 34% of the estuarine area of the United States. These effects include increased abundances of plankton, community changes in benthos, decreased abundances of fish, increased incidences of fish diseases, bioaccumulation of contaminants in fish tissue, fish kills, and marine mammal mortalities. Earlier, the results of the National Oceanic and Atmospheric Administration's Eutrophication Assessment [http://state_of_the_coast.noaa.gov/bulletins/html/eutro.html] showed that 22% of the Atlantic and

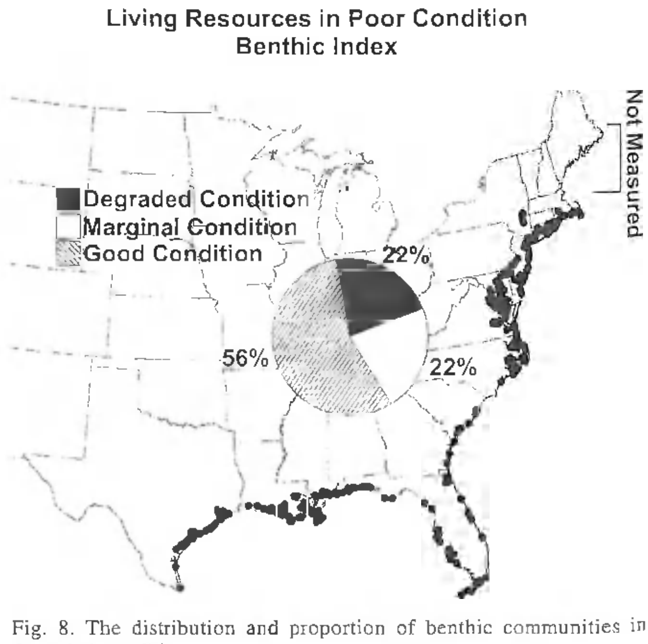

Fig. 8. The distribution and proportion of benthic communities in degraded condition.

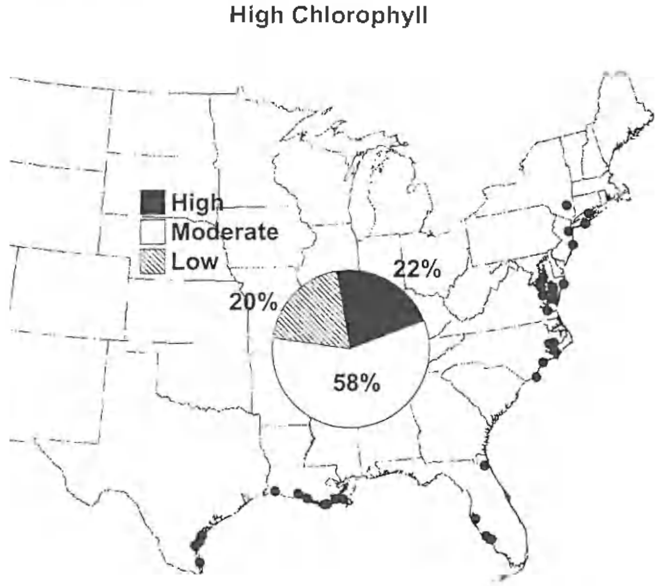

Fig. 9. The distribution and proportion of high concentrations of chlorophyll *a* (data from [http://state_of_the_coast.noaa.gov/bulletins/html/eutro.hmtl]).

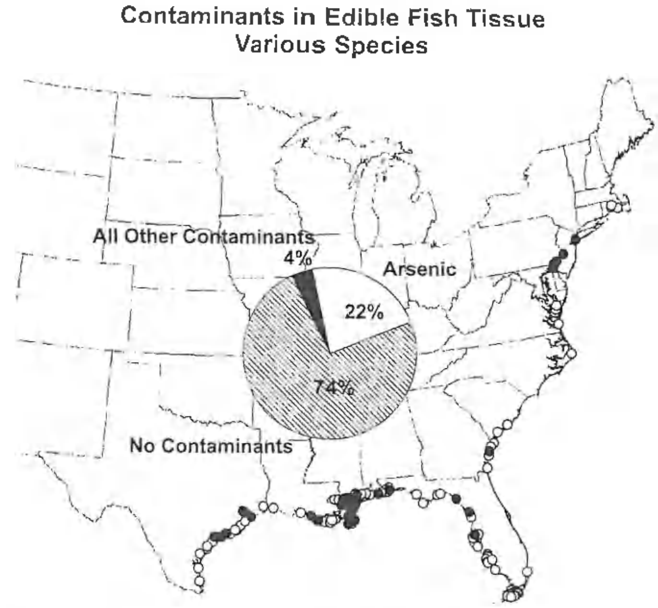

Fig. 10. Distribution of sites and proportion of fish examined by tissue residues that exceeded guidelines.

Gulf Coasts' estuarine areas had high concentrations of chlorophyll *a* (Fig. 9) and EMAP has shown that 22% of benthic communities in the Atlantic and Gulf Coasts' estuaries are in poorer condition than expected (Fig. 8).

The frequency and type of gross pathologies on fish taken in trawls in estuarine waters are indicators of overall condition of fish populations. Nearly 100,000 fish were examined from U.S. estuaries; only 454 of the fish (0.5%) had external abnormalities (Table 5). Of the fish examined, bottom-feeding fish (e.g., catfish) had the highest frequency of disease. The number of fish with multiple gross pathologies increased in areas where the sediments contain high levels of multiple contaminants.

Contaminant residues in edible fish tissue are perceived by the public as a negative quality for estuarine waters even if the concentrations are well below levels considered safe for consumption. The EMAP has compiled contaminant levels of pesticides, heavy metals, and PCBs for several groups of edible fish and shellfish in estuarine waters of the United States. In general, contamination concentrations in fish are low with the exception of some heavy metals (arsenic, chromium, mercury, and zinc). Twenty-six percent of estuarine fish populations show elevated levels of contaminants in their edible tissues (Fig. 10). Of these fish, 22% had elevated levels of arsenic in the edible flesh (as organic arseno-betenes that are not toxic to humans). Thus, only 4% of examined fish have nonarsenical toxic compounds in significant concentrations in their edible flesh.

Table 5. Proportion of fish examined with external pathologies, by province

Province	Number of fish	Percent with pathologies
Virginian	13,421	0.4
Carolinian	13,304	0.3
Louisianian and West Indian	64,100	0.7
Total	90,825	0.5

DISCUSSION

Six years of monitoring the estuaries along the Atlantic and Gulf of Mexico coastlines have shown that monitoring ecological indicators of condition at a regional scale can produce information that is useful to resource managers, particularly in identifying the extent of observed problems. The probability-based sampling design and standardized methodologies allowed for the collection of data that can be used in performing assessments throughout the United States with a quantifiable level of uncertainty. These surveys represent the first of their type in estuarine waters at large regional scales and with the capability of estimating condition with a known level of confidence. Other large-scale monitoring programs, such as the National Status and Trends Program of the U.S. National Oceanic and Atmospheric Administration, have stations that are located throughout the region or nation. These stations are fixed and cannot readily be used to integrate data regionally to assess overall condition. Only by assuming that these fixed sites are representative of the overall population can they be used to assess overall condition. Rarely can this assumption of representativeness be supported. Monitoring programs performed by individual states (with some exceptions, like Texas Park and Wildlife's Fish Survey, Austin, TX) are also based on fixed locations selected a priori based on known condition (e.g., a discharge is located at the site, a bridge traverses the estuary at that point, a buoy exists at this location). Prior to EMAP, estuarine regional assessments would have to bring together data collected from different programs, at different scales, using nonstandardized methodologies and attempt to integrate the information. Using the EMAP-type probability design, changes in status and trends in populations of estuarine resources can be determined within and between geographical regions. While this approach was applied at the biogeographic region spatial scale, it is equally useful at national, state, or local scales. To address these scales, the design simply must be adapted to the chosen scale or adapted, in a nested fashion, to represent multiple scales.

This form of re-adaptation of the EMAP approach to state and national scales is the basis for EPA's Coastal 2000 sampling program, which will assess the condition of estuarine resources within each of 25 coastal states and Puerto Rico over the period of 2000 and 2001. These data from the 25 states will be integrated in the first national assessment of estuarine condition with known confidence. Coastal 2000 and its predecessor, EMAP-Estuaries, represent the first attempt by a large-scale monitoring program to incorporate common sampling methods over large geographic areas to estimate ecological condition on an areal basis. By continuing these measurements, annually or on a fixed schedule (e.g., three to five years) through the coming decades, changes in ecological status and trends can be measured, assessed, and tracked objectively. This information can be used to determine whether the environmental programs and policies of the United States or individual states are effectively protecting and/or restoring the estuarine environment. Conversely, the information can indicate those programs that are not having the desired effect on the environment and can be used to modify, change, or restructure restorative efforts.

More research is necessary on the components of indices and their relationships to ecological conditions and environmental stressors to assess their stability, accuracy, and validity. These measurements, in combination with the probabilistic survey design approach, lie at the core of regional and national assessments of ecological condition. Through the Clean Water Act Plan, multiple federal agencies have designed a multiagency integrated research and monitoring program that will provide (1) the necessary research to continually improve these indicators, (2) the assessment techniques to better utilize them, and (3) a multispatial and multitemporal scale monitoring program to collect the data for all coastal resources [http://www.epa.gov/cwap]. The U.S. EPA's Coastal 2000 Program represents the first tier of this proposed monitoring plan for estuaries. Further development of surveys for beaches, coastal wetlands, and near-shore and off-shore coastal waters are called for in the Clean Water Act Plan itinerary.

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