CENTER FOR COASTAL MONITORING AND ASSESSMENT
science for coastal communities

Integrating and Communicating Results of Sediment Quality Triad Studies

Jawed Hameedi and Tony Pait
NOAA, Center for Coastal Monitoring and Assessment

EMAP Symposium 2004, Newport, RI
May 2004

MAJOR ENVIRONMENTAL ISSUES ACCORDING TO PUBLIC OPINION (Source: Gallup Poll News Service, 2000)

"Americans still favor environmental protection over economic growth"

- Air Pollution
- Water Pollution
  - Pollution of Rivers, Lakes and Reservoirs (85%*)
  - Contamination of Soil and Water by Toxic Wastes (84%*)
  - Ocean and Beach Pollution (75%*)
- Destroying Rain Forests/Trees
- Global Warming
- Ozone Layer
- Overpopulation
- Waste/Garbage
- Nuclear Waste
- Nothing
- Automobiles
- Oil/Oil Spills
- Acid Rain

———

* *indicates percentage of people who worry a "great deal" or a "fair amount" about the issue. A comparable figure for global warming is 33%.*

Principal Areas of Concern Relative to Marine Pollution in the United States (Pew Oceans Commission, 2001)

I. Toxic Contaminants

- Nature and amounts
- Biological effects
- Pollution abatement and remediation

II. Nutrient Pollution (biostimulants)

- Nutrient over-enrichment
- Ecological consequences
- Ammonia emissions: an emerging issue
- Abatement and control

III. Other concerns

- Oil
- Radio-isotopes
- Sediment
- Plastics and debris
- Thermal
- Noise
- Human Pathogens
- Non-indigenous species

Water Pollution Abatement and Control Costs in the United States

- Total Expenditures (1993): $38 billion

  By businesses: $26 billion

  By government: $12 billion
- Plus, $789 million spent on regulation and compliance monitoring
- Plus, $243 million spent on research and development

BUT

- Total costs continue to increase each year: $23 billion in 1983 to $32 billion in 1993 [constant 1987 dollars]

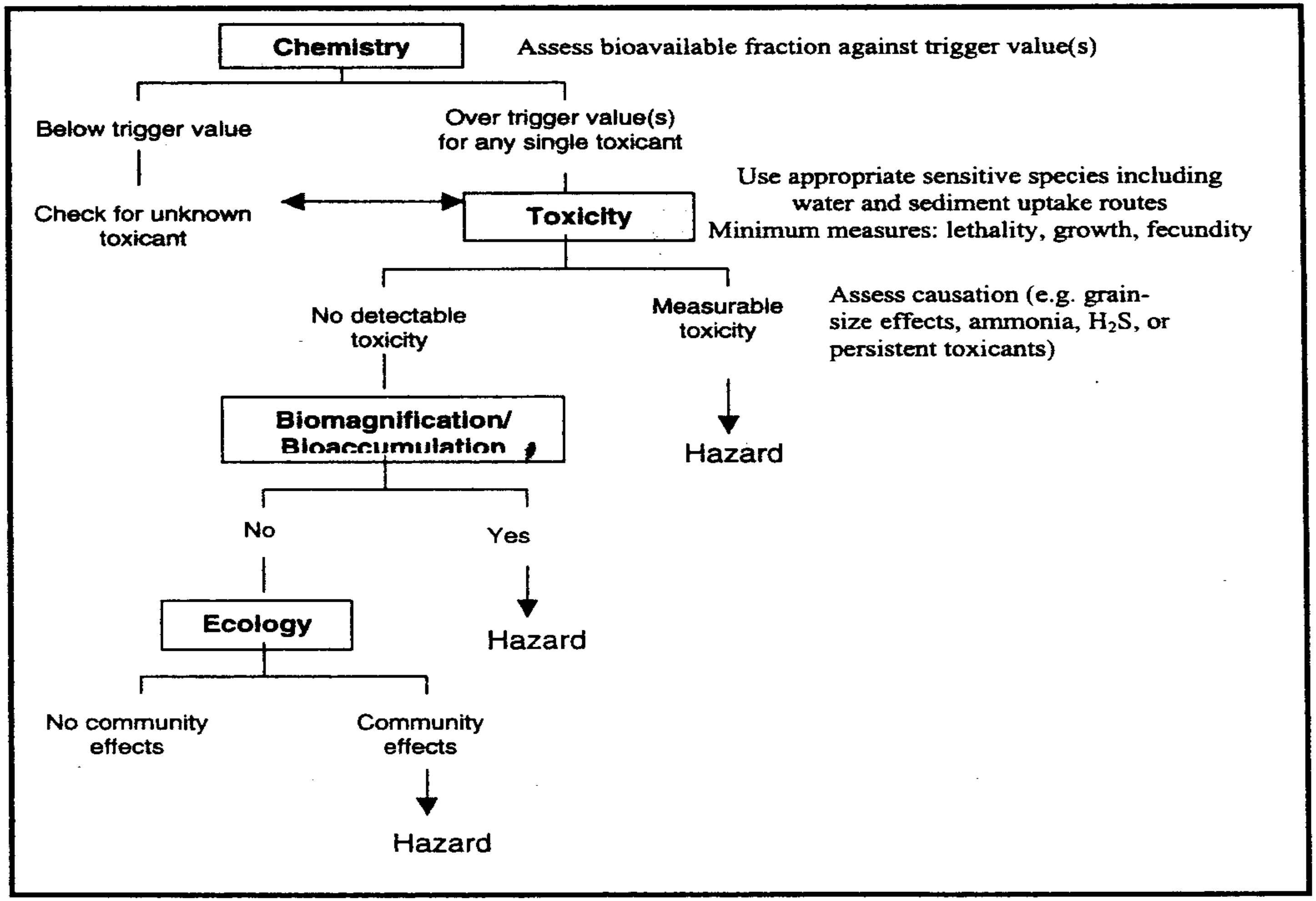
EXCEPT

- Research and development costs have declined steadily: $320 million (1992) to $243 million (1993) for water pollution; overall research and development funding (air, water, solid waste) continues to decline: $2,413 million (1980) to $1,438 in 1993 [in constant 1987 dollars]

Coastal Contamination and Sediment Toxicity
Legislation Pertinent to NOAA

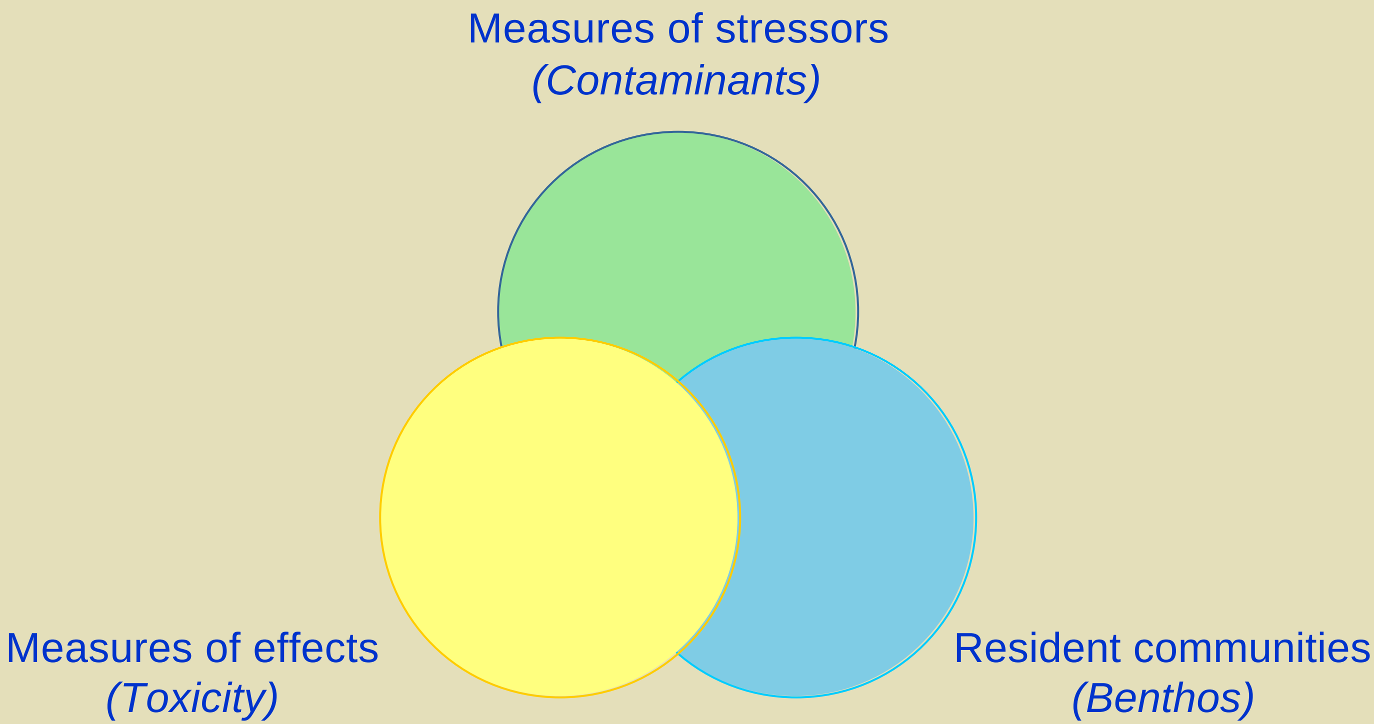
- Marine Protection, Research and Sanctuaries Act
  - Title II – Continuing program of research and monitoring
- National Oceanic and Atmospheric Administration Authorization Act of 1992
  - Title II – NOAA Ocean and Coastal Programs
    - (b) Observation and Assessment
  - Title V – National Coastal Monitoring Act
    - Essentially a codification of NS&T
- Water Resource Development Act of 1992
  - Comprehensive national survey of sediment quality in the United States
- Estuary Restoration Act of 2000
  - Section 2906 – develop and maintain database on estuary monitoring projects
- Coastal Zone Act Reauthorization Amendments (1990)
  - Section 2617: impacts of non-point source pollution on coastal water quality

A "Decision Tree" Approach for Toxicity Assessment – Regulatory Context (Batley, 2001)



Stepwise approach for "effects" assessment
(AMAP/EEA/ICES, 1999)

Starting Point for Assessment	**Known Contaminant(s)** **Known Source/Activity**	**Known Contaminant(s)** **Unknown Source(s)**	**Unknown Contaminant(s)** **Unknown Source(s)**
Initial Effects Assessment *(Is there evidence for biological effects?)*			Apply battery of screening tests
Detailed and Selective Effects Assessment (What is the spatial/temporal magnitude of effects?)	Perform focused tests relevant to specific contaminant	Perform focused tests relevant to specific contaminant	Perform focused tests selected on the basis of screening test results
Cause-Effect Identification			Reduce list of possible causative agents
Source Identification		Apply chemical finger-printing techniques, transport models, etc. to trace source of contamination	Apply chemical finger-printing techniques, transport models, etc. to trace source of contamination
Management Action			



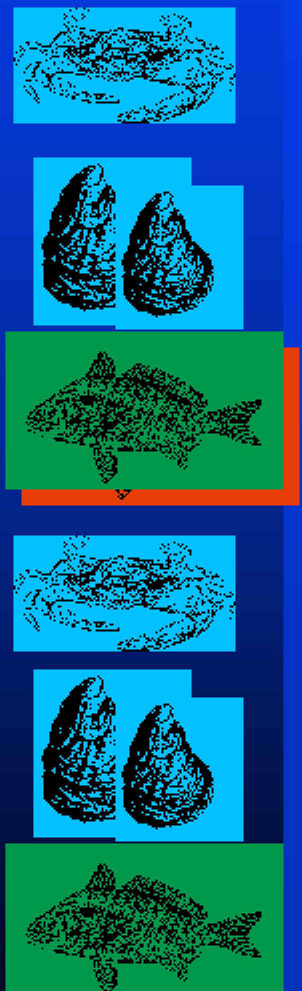
Sediment Quality Triad

(incorporates both observational and experimental data)

NOAA's Bioeffects Studies: Study Design

- Studies are conducted in specific coastal region using the following criteria:
  - *Mussel Watch data show high levels of contamination*
  - *State and local data indicate likelihood of adverse biological effects*
  - *Collaboration with other Federal, state and local agencies*
- Study area encompasses the entire waterbody, i.e., San Francisco Bay
- Sampling site selection is based on a stratified-random sampling design, i.e., each potential location in the study area has a non-zero probability of being sampled
- A synoptic set of contaminant, macroinvertebrate benthos, and toxicology data is obtained at each sampling site, i.e., the Sediment Quality Triad approach (Long and Chapman, 1985)

Spatial Extent of Sediment Toxicity



Toxicity Bioassays

- Amphipod survival (solid phase)
- Sea urchin fertilization and larval development (pore water)
- Microtox test (organic extract)
- HRGS-P450 bioassay (organic extract)
- Comet assay (DNA strand breakage)
- Juvenile clam mortality (whole sediment)
- FluoroMetPlate Bioassay (pore water)

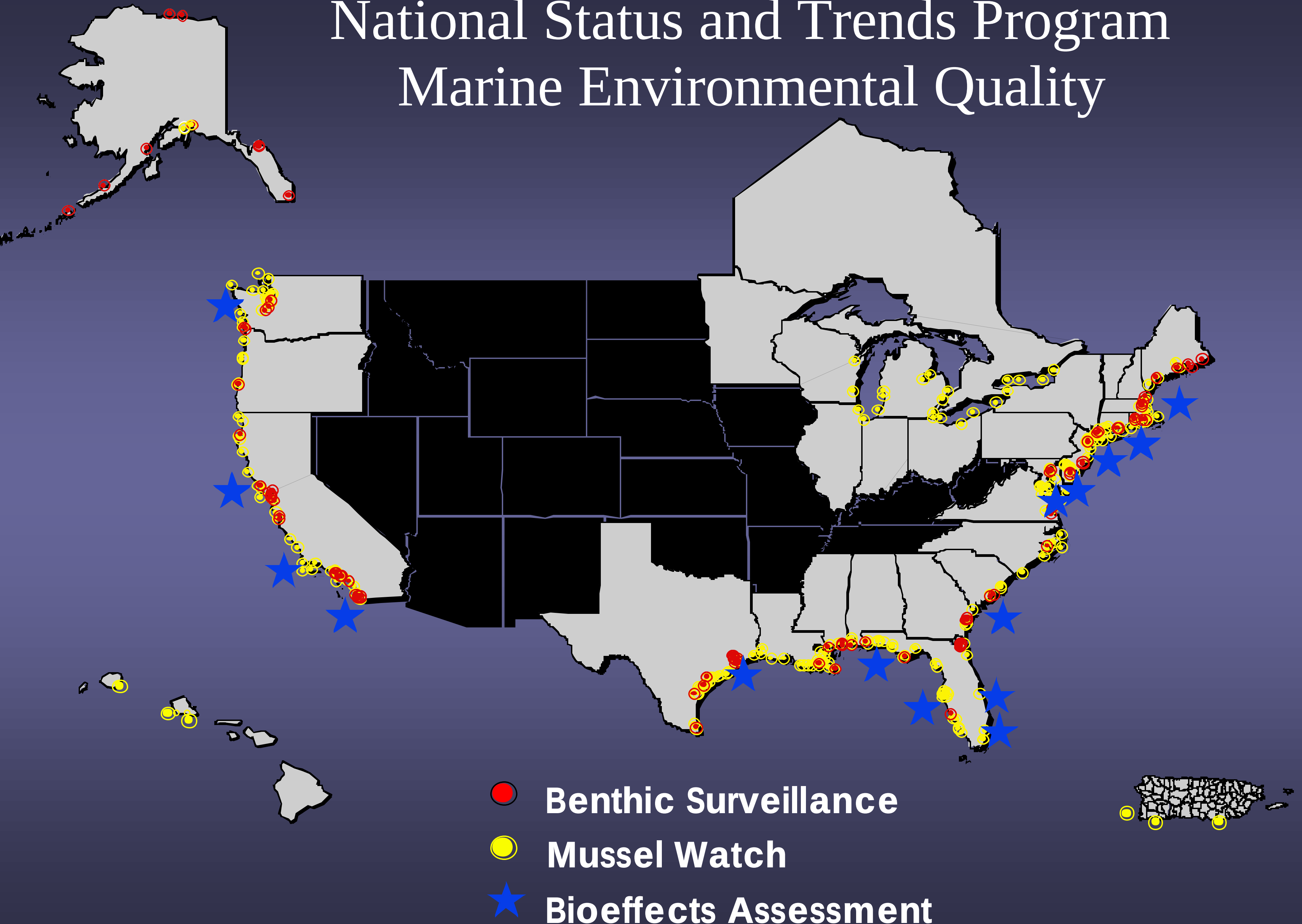
Contaminant Levels

- Trace elements
- Chlorinated pesticides
- Polychlorinated biphenyls
- Polycyclic aromatic hydrocarbons
- Butyltins
- [Dioxins, dibenzofurans, planar PCBs, PBDEs, APEs, PFOS]

Benthic Biological Community

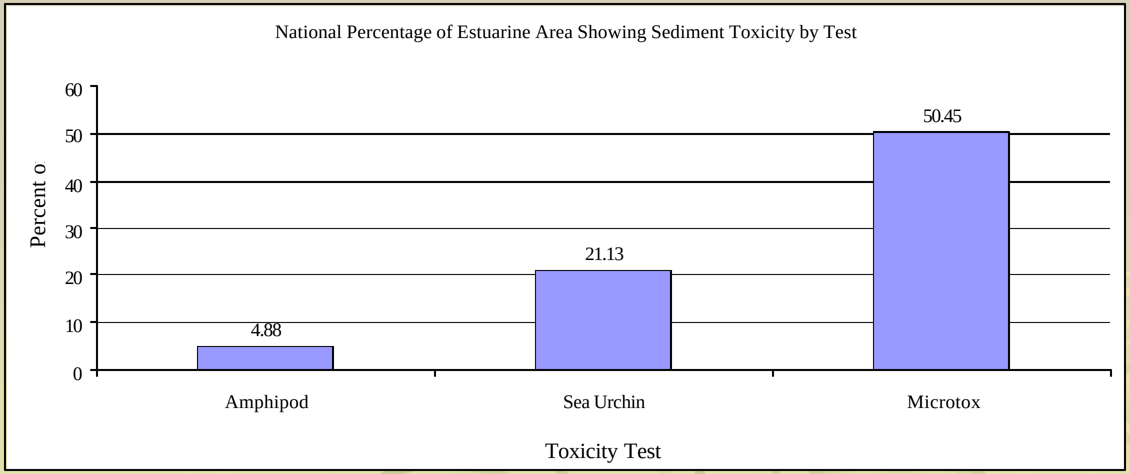
- Species richness
- Species diversity
- Indicator species (pollution tolerant, pollution sensitive)
- Benthic Index

National Status and Trends Program
Marine Environmental Quality

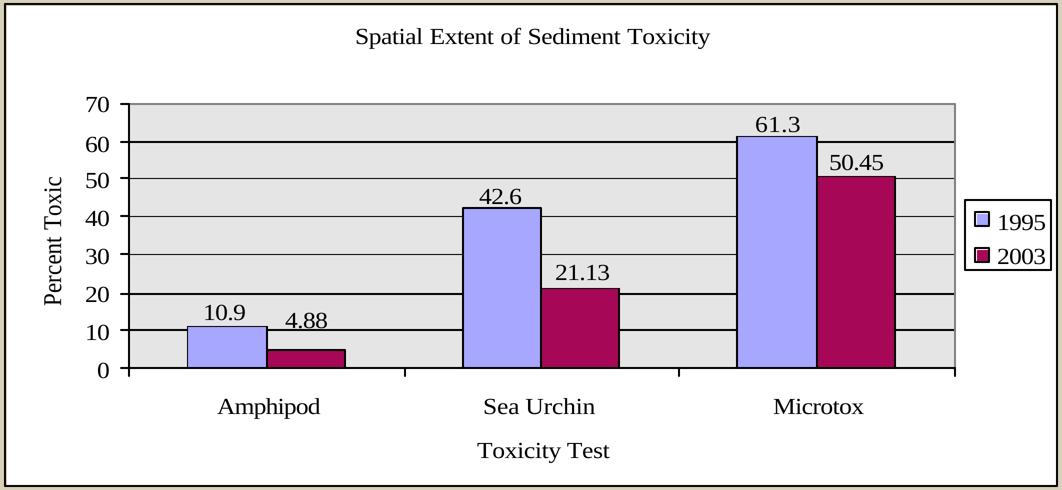


NOAA's Sediment Toxicity Assessment Studies

- Studied 25 coastal bays and estuaries, 1991-99 (area sampled: 8,750 sq km)
- Ongoing studies: Chesapeake Bay, San Francisco Bay, St. Lucie Estuary
- Geographically comprehensive (site selection is based on stratified-random sampling design)
- Synoptic measurements of contaminants, toxicity, and benthic community composition



Sediment Toxicity Assessment: NS&T and EMAP data



- EMAP Data (% degraded – amphipod test), from Long (2000)
  - Louisiana Province: 8.4
  - Virginia Province: 10.0
  - Carolinian Province: 2.0
  - California Province: -0- [NOAA: 58% in coastal bays]
- Cumulative EMAP: 7.3 (areas sampled: 64,000 sq km)

Qualitative Interpretation of the SQT Data

Contamination	Toxicity	Benthos	
Yes	Yes	Yes	Strong evidence of contaminant-induced degradation
No	No	No	Strong evidence against contaminant-induced degradation
Yes	No	No	Contaminants are not bioavailable
No	Yes	No	Unmeasured contaminants or conditions causing toxicity
No	No	Yes	Benthic alteration not due to contaminants

Estimates of the spatial extent of chemical contamination in Puget Sound, Washington (NOAA and State of Washington Cooperative Study)

	Samples	% Total	Area (sq km)	% Area
TOTAL STUDY AREA	300.0	100.0	2363.3	100.0
Effect Range-Median	39.0	13.0	30.7	1.3
Sediment Quality Standard				
-- All Chemicals	181.0	60.3	1256.0	53.1
-- Excluding Benzoic Acid, 4-methylphenol and phenol	62.0	20.4	139.8	5.9
Cleanup Screening Levels				
-- All Chemicals	160.0	53.3	1146.3	48.5
-- Excluding Benzoic Acid, 4-methylphenol and phenol	27.0	9.0	79.5	3.4
Any Criteria or Guideline				
-- All Chemicals	184.0	61.3	1259.5	53.5
-- Excluding Benzoic Acid, 4-methylphenol and phenol	70.0	23.3	143.7	6.1

San Diego Bay, CA

This region had widespread toxicity. Some areas of the bay near the Naval Station, near downtown San Diego, within boat basins and marinas, and with adjoining creeks and stormwater channels, were severely toxic. (Red = severe, yellow = moderate, green = slight, blue = non-toxic)

Sediment Quality Triad Workshop

(NOAA, September 1996; Chapman, et al., 1997)

- Among several topic of discussion:
- The utility of multivariate statistics in interpreting data
- Need for a broad, catholic index for presenting the data

Sediment Quality Triad Workshop

(NOAA, September 1996; Chapman, et al., 1997)

Workshop Outcome and Recommendation:

1. *Loss of information during data normalization and manipulation*
2. *Difficulty in explaining multi-dimensional space*
3. *Lack of transparency and abstraction of data (loss of details)*
4. *Potential misuse by "managers"*

- Therefore: A holistic index was not recommended
- Explore multivariate statistical analytical approaches

Limitation: TWO sets of variables

Possible Multivariate Approaches for Analysis of SQT Data

<u>Direct Methods</u>

Principal Component Analysis – PCA

(replaces a set of observed variables by a smaller set of derived "variables"; the analysis takes the variability of single set of variables and concentrates it in a few axes)

Factor Analysis – FA

(the observed variables are assumed to be linear combination of a set of unobserved variables plus a random error; not much used in ecology)

Correspondence Analysis -CA

(derived for use with categorical data, e.g., shapes of things; whereas PCA is primarily intended for continuous data)

Detrended Correspondence Analysis -DCA

(ensures that the second or subsequent axes have no relationship with previous axes; note that in PCA and CA, the second axis, which is mathematically derived to be linearly uncorrelated with the first, may in fact be a quadratic (or some other) variant of it; gaining popularity in ecology)

Possible Multivariate Approaches for Analysis of SQT Data

<u>Direct Methods (contd)</u>

Canonical Correlation Analysis - CCA

(extracts the correlation between two sets of variables and concentrates it in a few pairs of variables -- much too sensitive to non-linearity)

Procrustes Analysis - PA

(too much? stretching and rotating of data sets; gaining popularity in ecology)

Mantel's Test

(involves randomization; whether distance matrices correspond more than chance alone would suggest – index of association)

Nodal Analysis (Ian Hartwell and Larry Claflin)

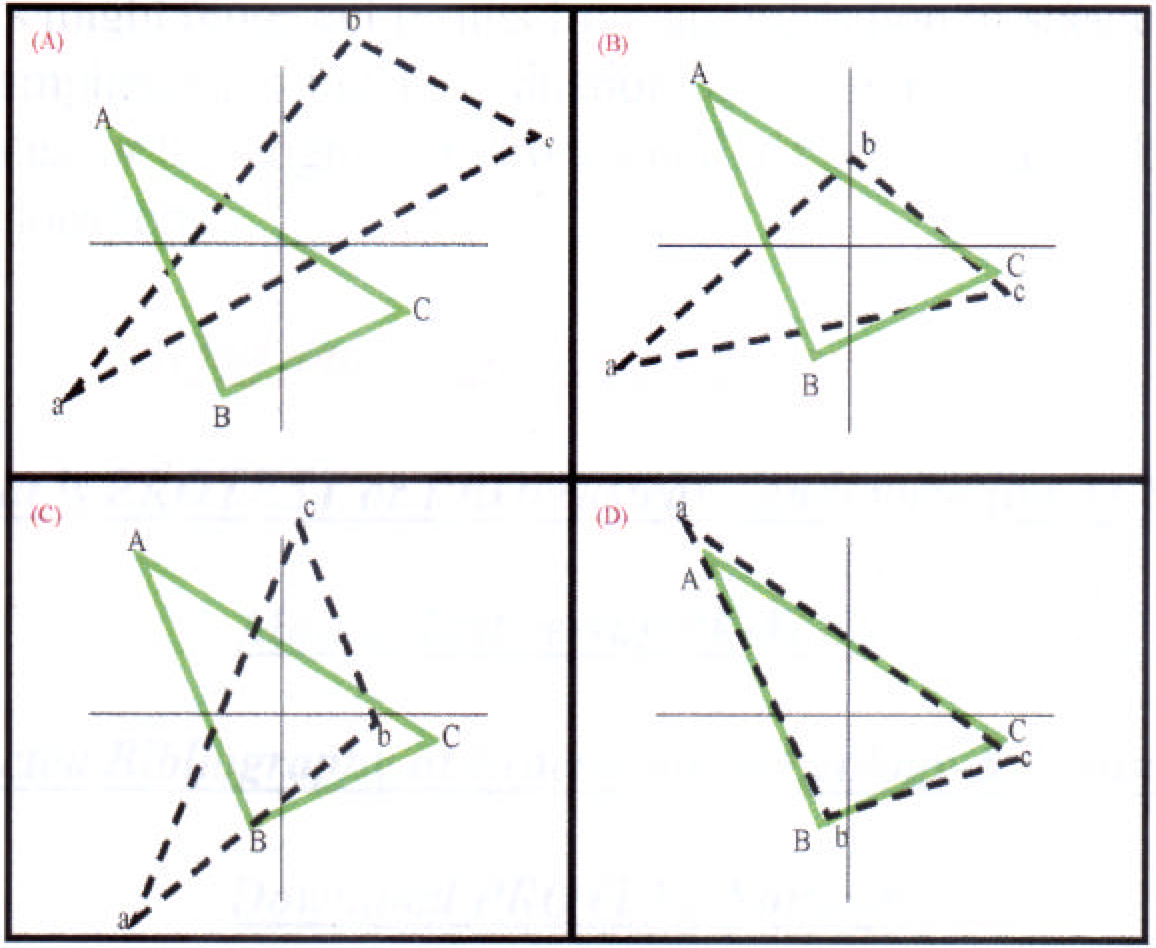
Possible Multivariate Approaches for Analysis of SQT Data

Indirect Methods: Two Step Procedure

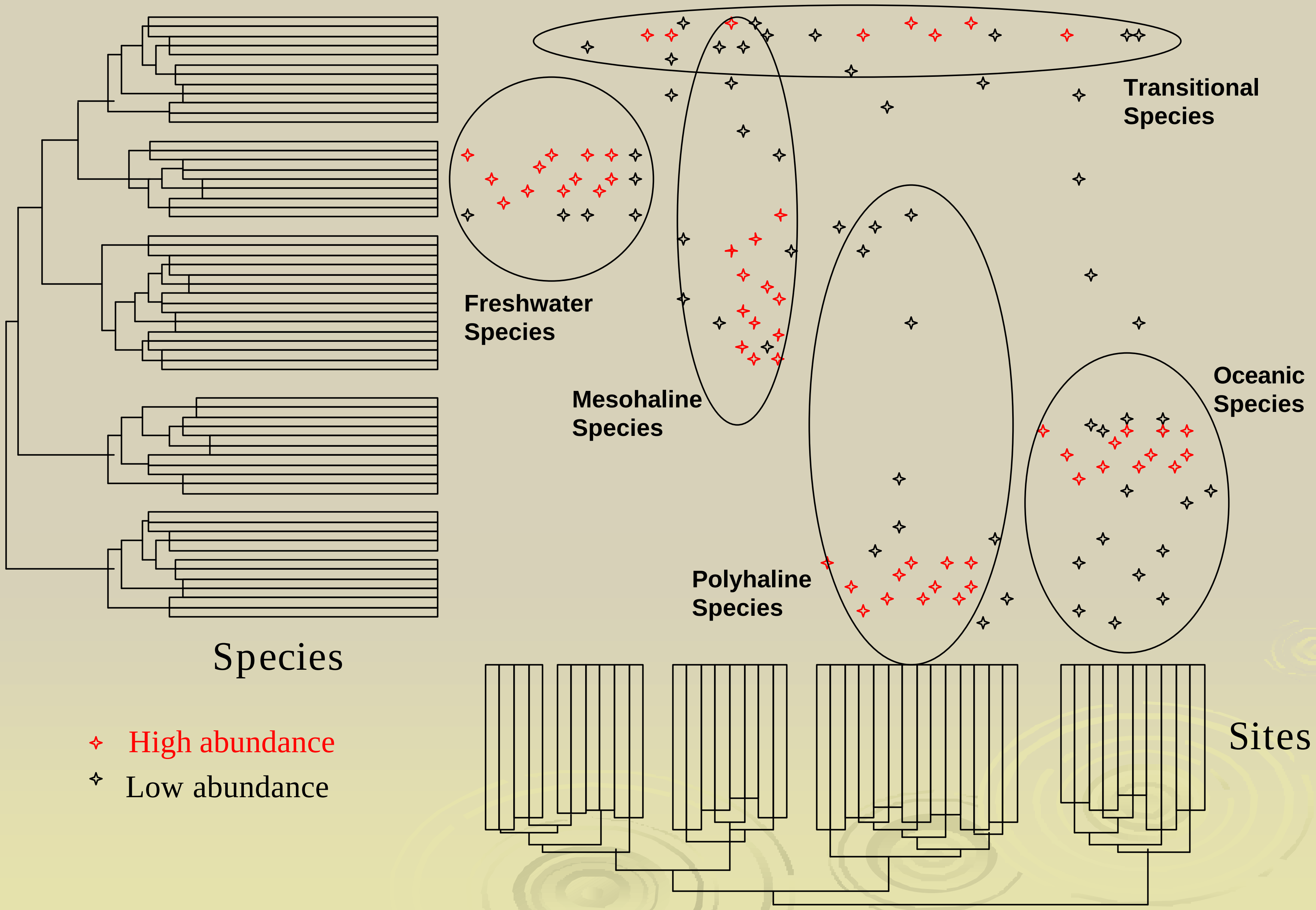
- *Describe the pattern within one or more sets of variables; then*
- *Relate the within set patterns to each other*

For example: cluster analysis followed by MANOVA

Procrustes Analysis: *Essentially a least square fit of one data matrix to another. The objective is to minimize the sum of the squared deviations between "landmarks" (could be stations) through translating and rotating one matrix (environmental variables) configuration to match the other (species). A small vector residual indicates a close agreement (Peres-Neto and Jackson, 2001)*



Nodal Analyses – Species/Site Associations



A Simplified Aggregate Index for Sediment Quality Triad Data (Hameedi and Pait, in progress)

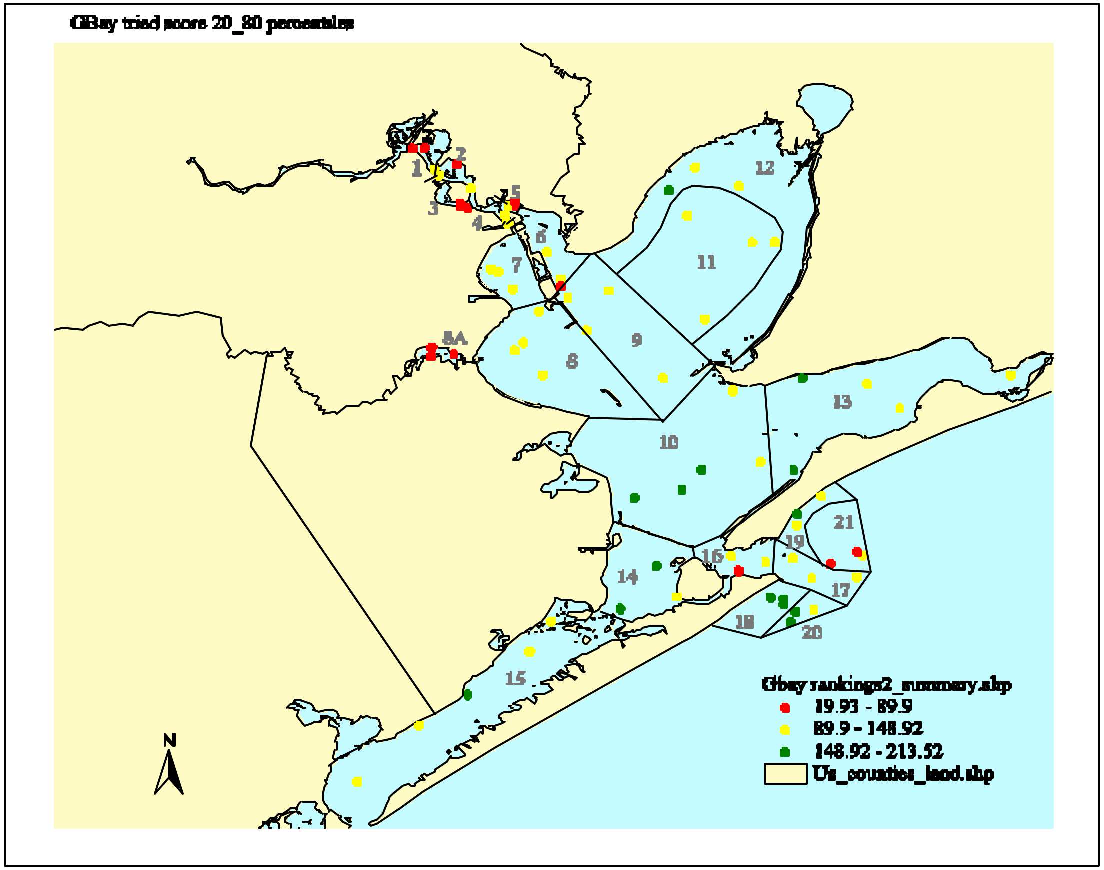
- Transform data for consistency and order in scales, i.e., lower values to indicate degraded conditions (e.g., low survival in a toxicity test; inverse of RGS response data; etc.)
- Scale data to a range of 0-99 using the formula:

  Scaled valued = ((initial value – minimum value) / (maximum value – minimum value)) x 99
- Determine average scores for aggregates of the three legs of the triad (or individual legs of the triad)
- Identify 20th and 80th percentiles of the scaled values and plot on map
- Make tri-axial plots of the scores for different strata or sites (smaller triangle indicates relatively degraded conditions)
- Estimate areas of the triangles to quantify the overall condition in a stratum (or at sites)

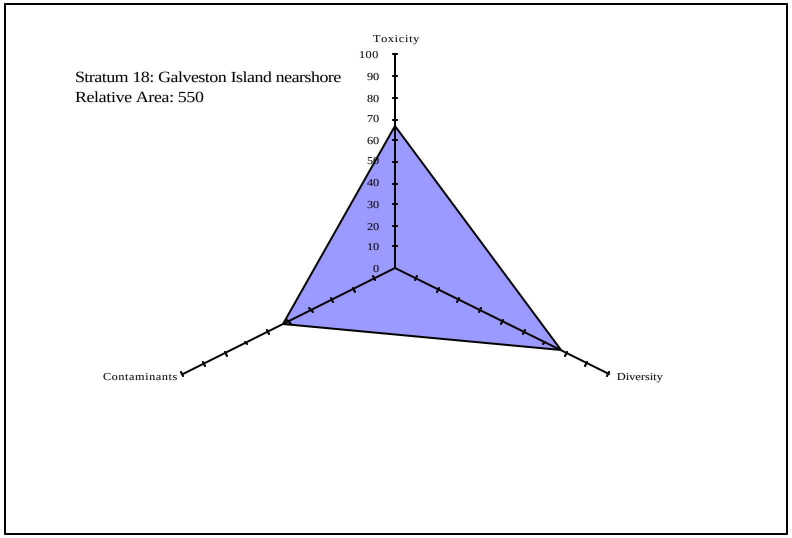
Aggregate Index for Sediment Quality Triad Data: Features

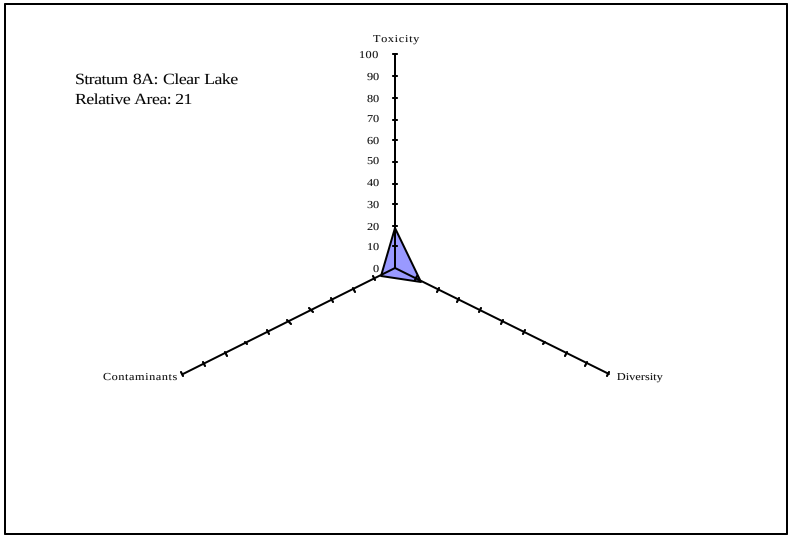
- Designed as a product for management use; it is not necessarily an ecological acumen
- Index relies on observed or derived values, not on their statistics
- Guidelines or “trigger values” are not used
- Index is transparent; i.e., disaggregation of its components is possible for detailed examination (cf. Factor Analysis)

SQT Data (GalvestonBay): Integrated Triad Scores



Aggregated SQT values for two sampling strata in Galveston Bay. Note the relative sizes and numerical values of the two strata (550 and 21)





Clear Lake, Texas

More than 400 waterbodies in the U.S. are named "Clear Lake" – most are not "clear" and many are heavily polluted

<u>Historically polluted (vicinity of NPL sites)</u>

Highlands Acid Pits

Benzene in groundwater: 210,000 ppb [5]

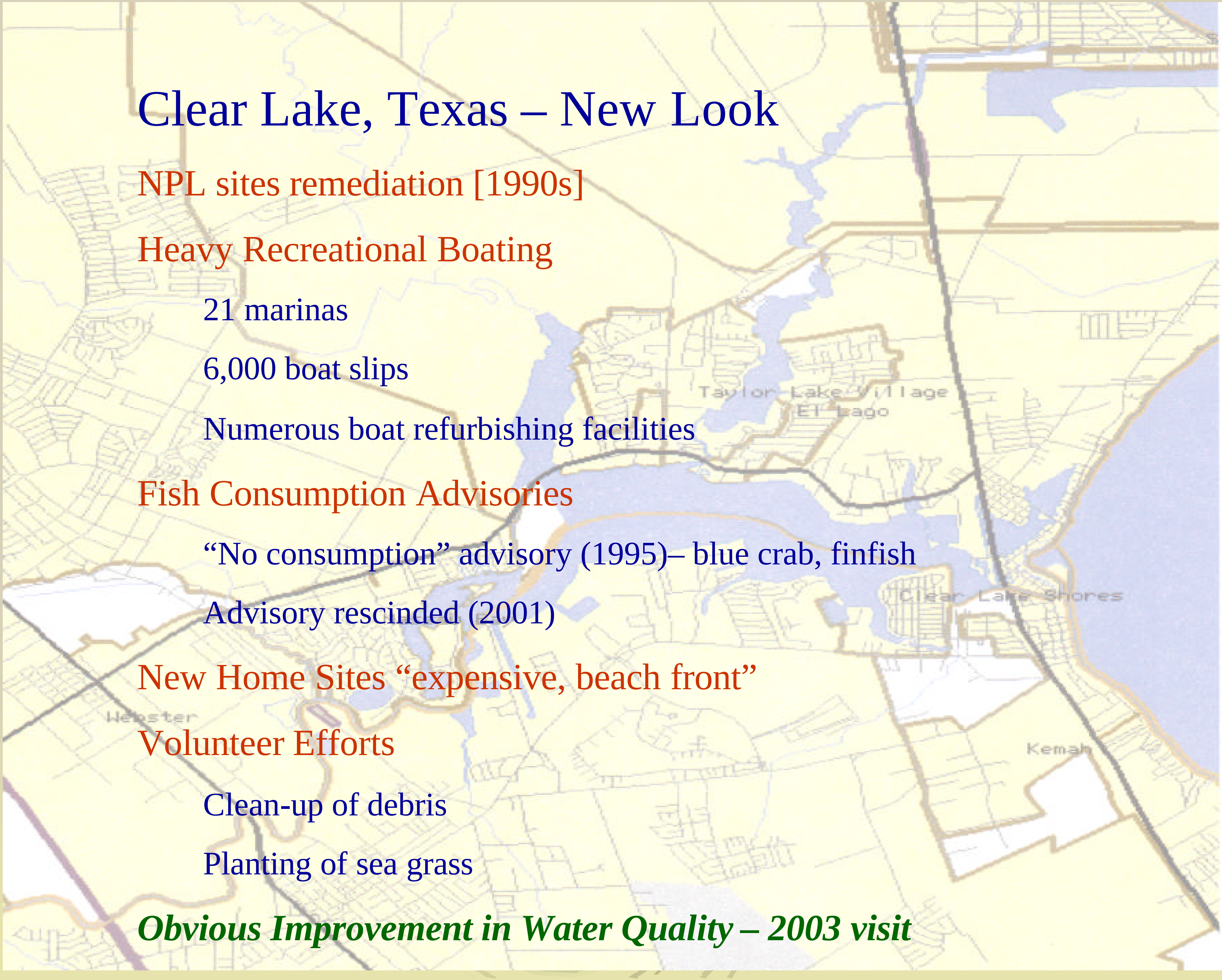
t-Xylenes in groundwater: 417,000 ppb [10,000]

Dixie Oil Processing

Copper in groundwater: 110,000 ppb [1,000]

Copper in soil: 98,900 ppm [100]

Clear Lake, Texas – New Look



NPL sites remediation [1990s]

Heavy Recreational Boating

- 21 marinas
- 6,000 boat slips
- Numerous boat refurbishing facilities

Fish Consumption Advisories

- “No consumption” advisory (1995)– blue crab, finfish
- Advisory rescinded (2001)

New Home Sites “expensive, beach front”

Volunteer Efforts

- Clean-up of debris
- Planting of sea grass

Obvious Improvement in Water Quality – 2003 visit

Epilogue: Clean Environment is Good for the Economy

- Commercial Fisheries Resources
  - Dockside value: $3 billion
  - Consumer Expenditures for fishery products: $55 billion
- Recreational Fishing
  - People: 17 million
  - Amount spent: $25 billion
- Enjoyment of Nature, Photography
  - People: 50 million
  - Amount spent: $10 billion
- Water Contact Recreation
  - People: 110 million-trips
  - Valued at: $40-50 billion
- Waterside Property
  - Value increases with improved water quality