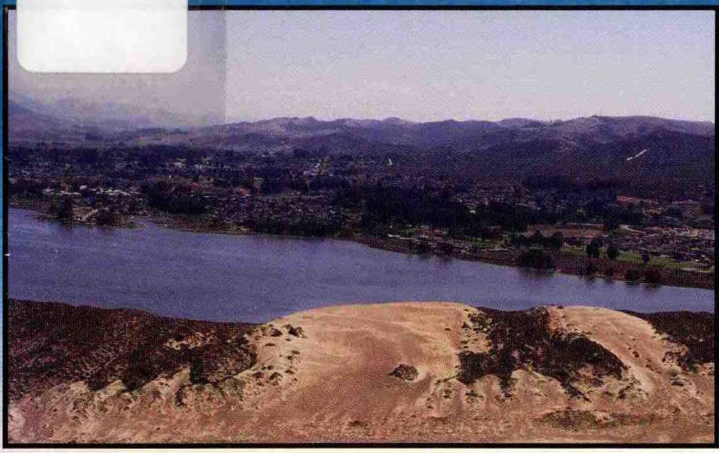
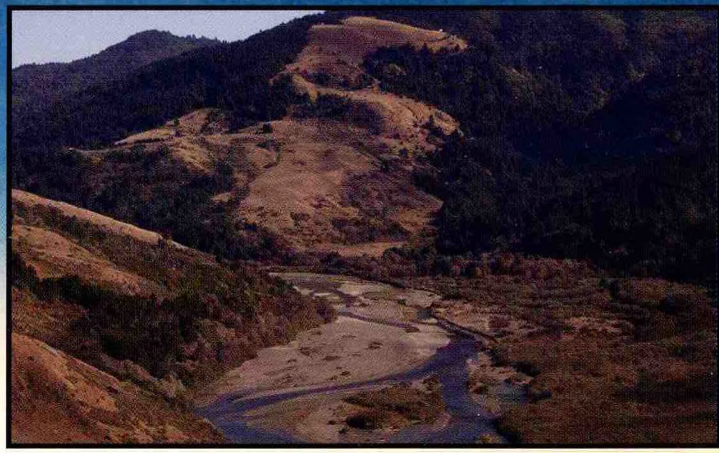
NATIONAL ESTUARINE EUTROPHICATION ASSESSMENT UPDATE:

Workshop Summary and Recommendations for Development of a Long-term Monitoring and Assessment Program





Proceedings of a workshop September 4-5, 2002
Patuxent National Wildlife Research Refuge, Laurel, Maryland

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
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TABLE OF CONTENTS

Executive Summary: *This document describes results and recommendations of the National Estuarine Eutrophication Assessment (NEEA) Update Workshop held by NOAA at the Patuxent National Wildlife Research Refuge in Laurel, Maryland on September 4 –5, 2002.*

EXECUTIVE SUMMARY

During recent decades, human activities have increased nutrient loads to estuaries and coastal waters many times above natural levels. These changes have caused a variety of impacts. Potential consequences of eutrophication range from ecological changes to socioeconomic impairments (e.g. fisheries) to serious human health threats. There is clearly a need to monitor and assess causes and consequences of nutrient related water quality conditions to provide the basis for effective management of this pervasive problem.

Workshop Intent and Objectives

The overall intent of the workshop was to discuss the design of a long-term monitoring and assessment program to address nutrient over-enrichment and consequent water quality problems in estuaries and coastal waters (Figures 1 and 2). This follow up program should address the question "To what extent do nutrient inputs to US estuaries and coastal waters impair society's uses of those water bodies?" by measurement and assessment of:

- Status and trends of water quality related to nutrient enrichment.
- Causes of observed problems (e.g. susceptibility, nutrient loadings).
- Socioeconomic impacts of nutrient related water quality degradation.
- Alternative management responses and the impacts of those alternatives.

Desired Outcomes

The framework developed at the workshop served as the basis for this guidance document which describes the development and implementation of the program including:

- Classification of types of estuaries and coastal water bodies.
- Appropriate variables for characterization of nutrient over-enrichment status.
- Assessment methods for determination of nutrient pollution status and trends, human use impairment, economic impacts, and causes of observed problems (e.g. loadings, susceptibility).
- Methods for translation and transfer of data/information from scientists to managers.
- Identification/development of a database or data access framework.
- Identification of long-term data sources.
- Identification of potential partnerships to support this long-term effort.

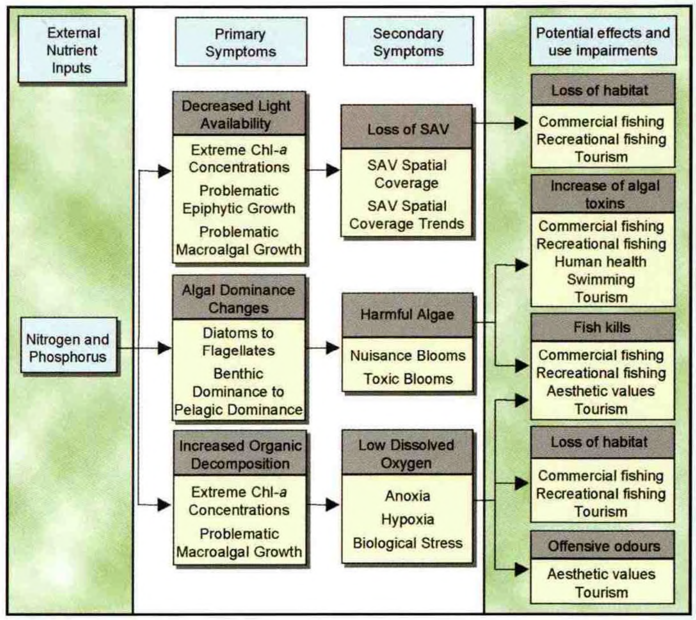

Figure 1. Conceptual model of eutrophication.

Discussion Topics

Workshop discussions, mostly in parallel breakout groups, were designed to address:

- **Definition of Eutrophication**
  Workshop participants fine tuned a definition and proposed an operational definition to be adopted for the program under development (see page 10).

- **Typology Development**
  Workshop participants identified a list of variables (hydromorphological and physico-chemical parameters) for consideration in the development of a type classification specifically to help in the assessment of eutrophic conditions. The main purpose for determining typology is that the

Estuarine Eutrophication: Nutrient Sources and Effects in Estuaries

Eutrophication is a process in which the addition of nutrients to water bodies stimulates algal growth. Under natural conditions, this is usually a slow process that results in healthy and productive ecosystems. In recent decades, however, a variety of human activities has greatly accelerated nutrient inputs to estuarine systems, causing excessive growth of algae and leading to degraded environmental conditions.

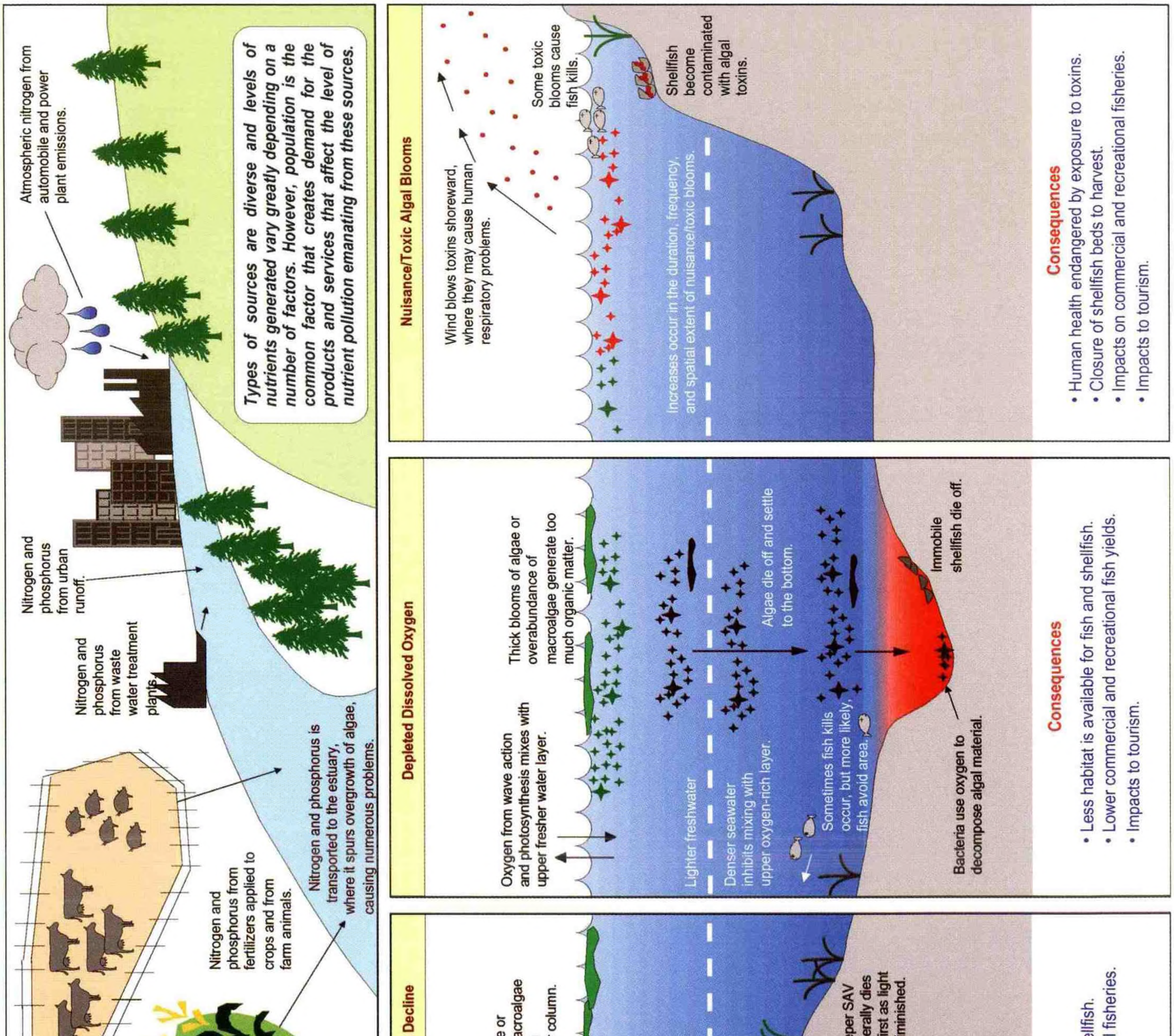

Figure 2. Nutrient sources and effects in estuaries (Bricker et al., 1999).

thresholds for eutrophication classes will vary according to type.

- **Monitoring, Assessment and Classification**
  Workshop participants discussed two monitoring assessment and classification topics:

  Nutrient related eutrophication
  A core set of variables that should be measured in all types of water bodies and an enhanced set of variables, to be used only if applicable, were developed by workshop participants. This includes measurement of loadings so causal linkages can be made between loading and water quality status. Assessment methods should be developed with these variables. Participants agreed to use NEEA methods and recent adaptations as a starting point for development of improved assessment methods.

  Socioeconomic impacts to human uses
  This component of the assessment was not included in the NEEA and requires further development. It was agreed that participation of additional social scientists and economists would be crucial in developing an appropriate approach to socioeconomic analysis.

- **Modeling and Management of Eutrophication**

  Models need to be developed to better understand and predict nutrient input/water body response relationships to guide management of human related eutrophication.

  Participants concluded that a proper adaptive management strategy for eutrophication must, besides having effective abatement measures, address two general themes:

  1. translation and integration of science into information and tools that are useful to managers, and
  2. reporting of results to the public and Congress to leverage action and funding for management and related research.

These discussions led to a recommendation that working groups be formed to address three categories of issues more thoroughly (see recommendations chapter for more detail):

1. Typology.
2. Monitoring, Assessment and Classification including variable selection and development of metrics and indices for nutrient related conditions and associated economic impacts.
3. Modeling and Management for better understanding of loading/response relationships, and to address what mangers need to successfully manage nutrient related issues in estuaries and coastal waters.

Next Steps

The development of a monitoring and assessment program for eutrophication assessment will include further development of typology, definition of relevant indicator variables (including reference conditions and classification), modeling, and management. The overall guidance for periodic assessments should include a component that assesses the socioeconomic impacts of eutrophication. Further development of these methods and models should be done through an appropriate selection of candidate estuaries for pilot studies.

INTRODUCTION

The Problem

Eutrophication is a natural process in which the addition of nutrients to estuaries and coastal waters from the watershed, atmosphere, and ocean stimulates algal growth. During recent decades, human activities such as fossil fuel burning and agricultural use of fertilizers have increased nutrient loads to many times natural levels. These changes have caused a variety of impacts; high levels of chlorophyll a (Boynton et al., 1982), overgrowth of seaweed and epiphytes, occurrences of anoxia and hypoxia (Gerlach, 1990; CENR, 2000), nuisance and toxic algal blooms (ORCA, 1992, Rabalais et al., 1996), and loss of submerged aquatic vegetation (SAV, Twilley et al., 1985, Burkholder et al., 1992b; Figures 1 and 2).

Potential consequences of eutrophication range from mere nuisances to serious human health threats. Anoxia related fish kills (Glasgow and Burkholder, 2000) cause noxious odors. Loss of seagrasses (Twilley et al., 1995; Burkholder et al., 1992b, Figure 3) and benthic organisms (Rabalais and Harper, 1992) may lead to long-term reductions in abundance, diversity, and harvest of fish in eutrophic systems (Brietburg, 2002). Algal toxins threaten human health if ingested in fish or shellfish tissue or when inhaled directly (Anderson et al., 2000). These impacts have been observed at varying levels in water bodies of the U.S. and many other countries (Table 1).

Measurable socioeconomic costs include economic losses to fisheries (Lipton and Hicks, 1999, 2003; Lipton, 2003; Mistaien et al., 2003), seasonal tourism, and the seafood industry (Anderson et al., 2000), while indirect and non-use values are more difficult to determine (Turner et al., 1999). Of particular concern, and a challenge to future management, are predicted increases in problems as coastal populations and use of fertilizers and fossil fuels continue to increase (Bricker et al., 1999; NRC, 2000; Boesch, 2002). There is clearly a need to monitor and assess causes and consequences of nutrient related eutrophic conditions to provide the basis for effective management of this pervasive problem.

Figure 3. SAV with colonizing algae (inset) and without.

Eutrophication Symptoms	System or Country of Observation
Toxic Algal Blooms	• Pamlico and Neuse River Estuaries (Burkholder et al., 1992a, 1995, 1999) • NE Coast of UK (Joint et al., 1997)
Nuisance Algal Blooms	• Lower Laguna Madre (Whitledge and Pulich, 1991) • Southern North Sea (Gillbricht, 1988) • Baltic Sea (Bonsdorff et al., 1997) • Mediterranean Sea (e.g. Lac de Tunis: Kelly and Naguib, 1984), • Northern Adriatic (Chiaudani et al., 1980), • Australia (Hodgkin and Birch 1982; Hodgkin and Hamilton 1993) • Japan (Okaichi, 1989; Okaichi, 1997)
Depleted Dissolved Oxygen	• Mississippi River Plume (Rabalais et al., 1996) • Chesapeake Bay (Cooper and Brush, 1991)
Loss of SAV	• Chesapeake Bay (Orth and Moore, 1983, 1984) • Tampa Bay (Greening et al., 1997) • Laguna Madre (Onuf, 1995)

Table 1. Example locations of Observed Eutrophic Symptoms.

This document describes the results of the National Estuarine Eutrophication Update Workshop held by NOAA at the Patuxent National Wildlife Research Refuge in Laurel, Maryland on September 4 –5, 2002. The purpose of the workshop was to discuss the design of a long-term monitoring and assessment program to address nutrient over-enrichment and consequent water quality problems in estuaries and coastal waters using the National Estuarine Eutrophication Assessment and recent methodological improvements (NEEA; Bricker et al., 1999, Bricker et al., 2003.) as a starting point.

The follow up program should be designed to address the question "To what extent do nutrient inputs to US estuaries and coastal waters impair society's uses of those water bodies?" It should also address management of human related eutrophication in areas that are impacted. This program should include measurement, assessment, and modeling of water quality related to nutrient enrichment, the impacts of nutrient related water quality degradation on human uses of estuaries, the sources of nutrients to water bodies and factors that influence development of nutrient related problems, and the development of appropriate management responses. There were 40+ participants, resource managers and scientists, from federal and state agencies, and universities who were specifically chosen for their experience, knowledge, and geographic location (see participant list, inside front cover).

THE WORKSHOP

After introductory remarks by Dr. Gary Matlock, Director of the National Centers for Coastal Ocean Science (NCCOS), three speakers made presentations entitled:

1. "What data and information do managers need in order to address coastal nutrient pollution and over-enrichment?" (David Keeley, Maine State Planning Office).

2. "Application of the National Estuarine Eutrophication Assessment (NEAA) to some European estuaries." This presentation demonstrated the use of statistically determined quantitative values calculated from data, GIS for calculating area weighted scores rather than expert knowledge, and a simple hydrological and exchange model to determine anthropogenic pressure and assimilation capacity of the systems." (Joao G. Ferreira, Institute of Marine Research, Portugal; Bricker et al., 2003).

3. "Measuring the economic impacts of eutrophication". This presentation showed the economic impacts of nutrient-enrichment in Chesapeake Bay using the Striped Bass recreational and Blue Crab commercial fisheries as examples. (Doug Lipton, Department of Agricultural and Resource Economics and Sea Grant Extension, University of Maryland; Lipton and Hicks, 1993, 2003; Lipton, 2003; Mistaien et al., 2003).

The participants worked in breakout groups for the remainder of the two day workshop, discussing the objectives of the program being designed and making recommendations on how to proceed.

Objectives

The focus of the workshop was to develop a monitoring and assessment program, including plans for periodic assessment updates that would be the basis for evaluation of trends in nutrient related water quality issues, with important implications to the management of estuarine and coastal resources. The update components include: assessment of status and trends in nutrient related water quality, causes of observed problems (i.e., nutrient inputs, physical processing), consequences to water quality and to human uses of estuaries and coastal waters (if nothing is done), and alternative management options and the impacts of those alternatives. Consequently, three breakout groups, working mostly in parallel, addressed the following issues:

- The definition of "cultural eutrophication" or "human-induced nutrient over-enrichment" including what variables "define" eutrophication and what are the thresholds that characterize an estuary/coastal water as eutrophic.

- Classification of estuaries/coastal waters by physical/chemical characteristics into groups that behave similarly such that models of nutrient input/water body response might be determined (i.e., development of an appropriate typology).

- The data and information, most useful format, and the temporal and spatial scales of data and information that are needed by managers to do their jobs efficiently and successfully, and how scientists can better provide what managers need.

- Appropriate variables, variable characteristics, and methods to accurately characterize nutrient over-enrichment including core and enhanced sets of variables, and temporal and spatial scales for sampling.

- Assessment methods and models for linking nutrient related water quality degradation with impacts to society's uses of estuaries/coastal waters including cost benefit analyses.

Desired Outcomes

The principal desired outcome was the development of a framework for a long-term monitoring and assessment program to address the question of whether, and to what extent, nutrient inputs are causing impairments to society's uses of estuaries. The framework developed at the workshop served as the basis for this guidance document describing the development and implementation of the program including:

- Appropriate variables for characterization of nutrient over-enrichment status.

- Assessment methods for determination of nutrient pollution status, susceptibility to nutrient over-enrichment, human use impairment, trends in nutrient pollution status, and economic impacts of nutrient related water quality problems.

- Models for understanding nutrient input/water body response that can be used in predictive and management capacities.

- Methods for measurement of sources and amounts of nutrient loading to explain nutrient pollution status and trend data.

- Methods for timely delivery and appropriate formatting of data and information from scientists to managers.

- Identification/development of a database or data access framework.

- Identification of long-term data sources.

- Identification of potential partnerships to support this long-term effort.

OVERALL RECOMMENDATIONS

While most of these topics were touched on during the two days of discussion, there was inadequate time for full consideration of all program components. What follows are summaries of each of the discussions by topic, and recommendations for how to proceed, based on the group's discussions.

1. Develop a quantitative monitoring and assessment program to provide the basis to address nutrient related eutrophication in US estuaries, embayments, and other coastal waters (including Great Lakes as well as Alaskan and Hawaiian systems). This program should be viewed as interactive with, and a companion program to, the National Research Program for Nutrient Pollution in Coastal Waters (Howarth et al., 2003).

2. Program development should proceed on two simultaneous and related tracks:

   - Typology (classification) which will lead to variable selection for assessment of nutrient related eutrophication, appropriate spatial and temporal sampling scales, appropriate assessment methods, development of nutrient input/water body response relationships, and predictive models for different input scenarios for the different water body types, and

   - Identification of linkages and relationships between: nutrient-impaired water quality, their impacts on estuarine and coastal resources, and consequent impacts on society's uses of estuarine and coastal resources.

3. Partnerships should be identified and developed to assure long-term funding and should use prior experiences of other programs to develop broad scale consistency. For instance, the EPA Office of Water's development and implementation of nutrient criteria and total maximum daily loads (TMDLs; http://www.epa.gov/owow/tmdl/) may benefit from a program such as this and vice versa. A product of those partnerships could be an overall national approach to assess and manage eutrophication that combines assessment approaches (e.g. NEEA update) and management aspects (e.g. US EPA Atlantic Ecology Division [AED] Development of regional nitrogen input limits for estuarine and Great Lakes coastal systems).

4. Convene sub-groups to tackle details of :

   - Typology classification that captures system variability in a context that is useful for the assessment and management of eutrophication.

   - Monitoring, Assessment and Classification including selection of variables and assessment methods appropriate for describing: 1) nutrient related eutrophication, and 2) consequences of impacts, such as the relationships between society's uses and nutrient related impacts on estuarine/coastal waters.

   - Modeling and Management of eutrophication for better understanding of nutrient input/water body response and other relationships that elucidate causes of, and management solutions to, eutrophication which should include a clearer definition of manager's needs (information and tools) and impacts of alternative management actions, including if no action is taken.

5. Develop the impact component (i.e. human use impairment) of the assessment, particularly the link between nutrient related water quality degradation and society's uses of estuaries and coastal waters. Participants agreed that additional economists and social scientists should be brought into the group to provide the experience and knowledge needed to develop the approach and methods for the envisioned national scale evaluation of the link between nutrient pollution and economic costs.

6. Issues should be addressed on three levels as for the NEEA (Bricker et al., 1999; NOAA 1996, 1997a, b, c, 1998): individual estuary, regional, and national. Program results should maintain local relevance and must provide data and information to resource managers in a timely way and in a useful format.

7. Develop tools for use by resource managers, such as models of the link between nutrient loading and fish production, and between nutrient loading and loss of submerged aquatic vegetation.

8. Conduct a pilot study to further develop and test assessment methods developed by sub-groups in a variety of systems representing the diversity of types of estuaries along the US coast. Candidate estuaries must have an existing robust database.

9. Learn from work done to implement the European Union Water Framework Directive (WFD 2000/60/EC, e.g. COAST, 2003; Bettencourt et al., in press.; Ferreira et al., 2003) and the Oslo-Paris Convention for Protection of the Marine Environment of the North-East Atlantic (OSPAR, 2002). In these fora much work has already been done regarding typology, reference conditions and threshold determination, as well as classification of eutrophication status using statistically determined quantitative values calculated from data, GIS for calculating area weighted scores, and simple hydrological and exchange models to determine anthropogenic pressure and assimilation capacity of the systems.

10. Improve public outreach concerning causes and consequences of nutrient over-enrichment to develop public support for management through: identification of the problem, development of solutions, implementation of solutions, and outcomes or status of implementation on estuarine and coastal resources.

TOPICS OF DISCUSSION

Definition of Eutrophication

Workshop participants agreed that there were several existing definitions of eutrophication that would be adequate, with some revisions. The definition on page v in the Executive Summary of the NEEA (below, Bricker et al., 1999) was used a starting point and the definition refined based on some additional considerations (see box).

Eutrophication is the accelerated production of organic matter, particularly algae, in a water body. It is usually caused by an increase in the amount of nutrients being discharged to the water body. As a result of accelerated algal production, a variety of impacts may occur, including nuisance and toxic algal blooms, depleted dissolved oxygen, and loss of submerged aquatic vegetation. These impacts are interrelated and usually viewed as having a negative effect on water quality and ecosystem health.

Some additional considerations for enhancing the definition follow:

- Need to focus on the anthropogenic side (i.e. "cultural" eutrophication),
- Couple susceptibility/sensitivity with the level of enrichment,
- Should call eutrophication "nutrient enrichment", "nutrient over-enrichment", or "nutrient pollution",
- Should use climatology in determination of cultural eutrophication in the context of departure from long-term average conditions,
- Add Nixon's definition (i.e., eutrophication is the accumulation of organic matter from anthropogenic inputs, or as an increase in organic matter in the water column),
- Include the undesirable effects of nutrient over enrichment and add quantitative measures,
- Definition should include a section on the meaning of the word for management purposes,
- Definition should include nutrient forcing and management goals.

The following definition incorporates recommended revisions and should be adopted for the program under development:

Eutrophication is a natural process by which productivity of a water body, as measured by organic matter, increases as a result of increasing nutrient inputs. These inputs are a result of natural processes but in recent decades they have been greatly supplemented by various human related activities. Cultural eutrophication, or nutrient over-enrichment, is the enhanced accumulation of organic matter, particularly algae, that is caused by human related increases in the amount and composition of nutrients being discharged to the water body. A variety of impacts may result, including nuisance and toxic algal blooms, depleted dissolved oxygen, and loss of submerged aquatic vegetation and benthic fauna. These impacts are interrelated and usually viewed as having a negative effect on water quality, ecosystem health, and human uses. Management concerns should address the human, or cultural, portion of nutrient additions insofar as the additions are detrimental to the environment.

Typology Development

Development of a type-classification for estuaries and coastal waterbodies is the cornerstone to the development of the assessment and monitoring program because the waterbody type will dictate the appropriate variables to monitor, the sampling time frame and spatial scale, and appropriate management actions. The classification scheme should capture the system variability in a context that is useful for the assessment of eutrophication and should be quantitative in nature (Figure 4).

A list of hydromorphological and physico-chemical variables (below) was identified for consideration in the development of types of characteristic estuarine and coastal waters (including the Great Lakes). While the quality of the receiving water body (i.e. unimpacted levels of; nutrients, Chl a, etc) is not included here, it might be considered since these conditions clearly separate systems such as Florida and Hawaii from others with naturally higher level nutrients and Chl a. Additionally, coastal waters should be considered along with estuaries in order to include descriptions of the diversity of water body types that were included in the NEEA as some are not traditional estuaries.

Figure 4. Photos of four different types of systems. (Pictures 2,3,4 clockwise from upper left: copyright© 2002 Kenneth Adelman, California Coastal Records Project, www.californiacoastline.org)

The philosophy for development of the list of variables was to review the obvious types within regions to ensure that all major types would be described, and then look for variables that might be used to develop an objective classification scheme to capture these types rather than a "one size fits all" approach. The resultant list of hydromorphological and physico-chemical variables that should be considered for description of water body types is*:

1. Latitude and longitude
2. Basin shape
3. Depth
4. Volume
5. Water residence time
6. Tidal range
7. Climate and seasonality (temperature, light, photo-period, precipitation)
8. Sediment substratum (type and rate of accumulation)
9. Ratio of catchment size to surface area of estuary
10. Discharge (flow source, magnitude, pattern, quality) to estuary scaled to area or volume of estuary
11. Climatology of salinity immediately outside the system (i.e., offshore adjacent coastal waters) at monthly to quarterly time frames
12. Salinity within the waterbody
13. Wave climate (sheltered or exposed)
14. Potential Habitat (i.e. what habitats would be there in the absence of human intervention)
15. Stratification (seasonal)
16. Sea ice/Ice coverage

*note that the quality of receiving waters is not included but might be an additional variable given that ambient or unimpacted conditions (e.g. nutrients) might be useful for classification of types of systems with very low natural levels or those with naturally high levels due, for instance, to upwelling.

Recommendations:

- Convene a sub-group of the Update Workshop participants, plus others who might be appropriate, to proceed with development of a typology classification metric or formulation. There should be overlap between this group and the Variable sub-group to maximize use of data and to validate typology descriptions.

- Use previous NOAA susceptibility work (eg., Quinn et al., 1989), previous LOICZ (http://www.kgs.ukans.edu/Hexacoral/Envirodata/envirodata.html, http://

data.ecology.su.se/MNODE/), and European work (eg; COAST, 2003; OSPAR, 2001) as a starting point. Everything else follows from the typology, including selection of variables for eutrophication assessment, sampling scheme (spatial and temporal), assessment, classification, models and management implication.

- Use system parameters (residence time, volume, depth, stratification, etc.) that affect the system sensitivity to nutrient loading rather than classical geomorphological classes (coastal plain estuary, lagoon, etc.) for typology classification. Classes defined by these two approaches overlap to some extent, but they differ in their emphasis. Selected variables should be sub-divided into quantitative ranges (categories) with thresholds for ranges set by common agreement based on expert knowledge or other approaches. The parameter-based approach lends itself better to mathematical expression, and therefore to mathematical model building.

- Typology should not include water quality issues reflecting degradation which can be added as a data layer once the classification is complete, though ambient or unimpacted levels of nutrients might be useful for separation into types where concentrations are naturally very low, or high due to upwelling.

- Human modification of systems should be noted (modified systems may be a "type"). Modified systems might be identified by degree of pressure (e.g., number of persons per area or volume) or degree of response (e.g., percent change in primary productivity due to pressure) or degree of structural change (e.g. percentage of shoreline modification).

- Limit the total set of types to a manageable number (fewer than 10 "common" types).

Monitoring, Assessment and Classification

Development of assessment and classification methods is a first step toward development of a program that integrates the science and management of nutrient related problems through appropriate monitoring, assessment, modeling, and research. Assessment methods will be used to classify the status and to track nutrient-related problems over time, with the intent of guiding development and evaluating the success of management actions and in support of research. Additionally, modeling will be helpful for understanding how human impacts of eutrophication can be more effectively managed (Figure 5).

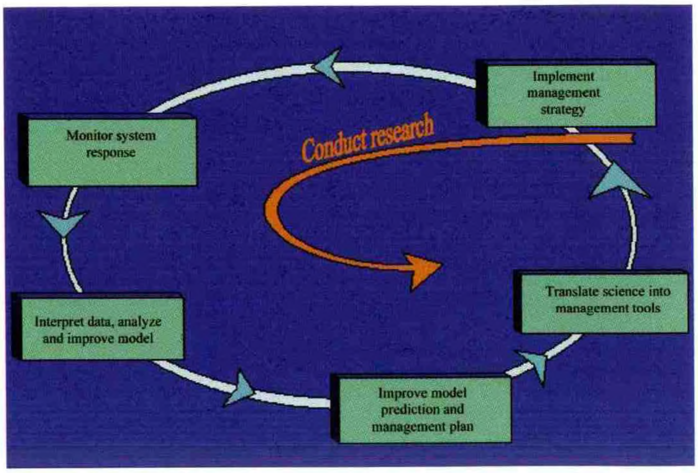

Figure 5. Flow diagram for adaptive management framework.

The type classification should be a first step since the variables appropriate for accurately characterizing nutrient related water quality conditions are ultimately type related, as are appropriate spatial and temporal considerations for sampling (Figure 6).

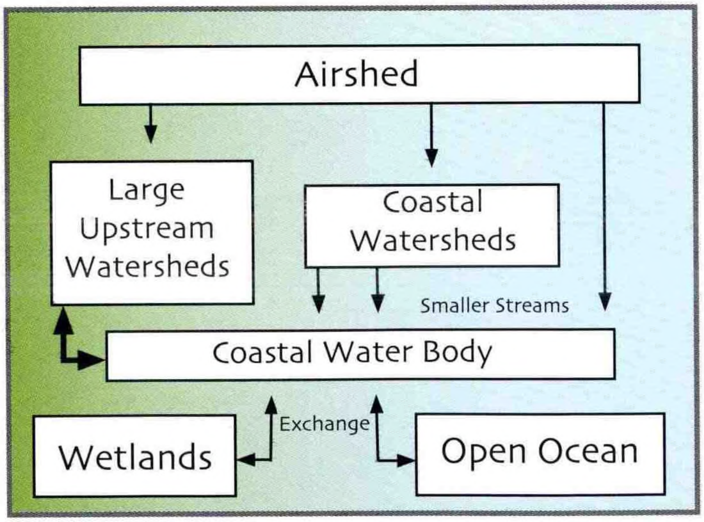

Figure 6. Schematic showing general sources of nutrients and main route of transport to coastal waters.

Nutrient Related Eutrophication

Workshop participants developed two lists of variables; a core set of variables that should be measured in all types and an enhanced set of variables that is specific to a type of estuary/coastal water or its specific eutrophication status (see lists following; Figure 7). It should be noted that some core variables may not be applicable to all types

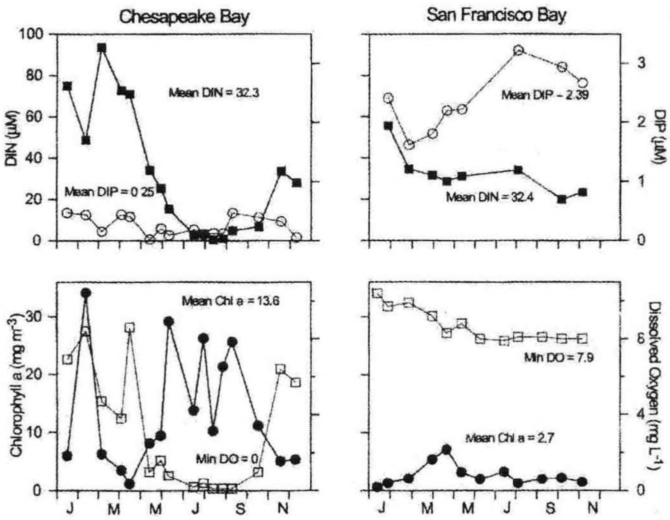

Figure 7. CHL a, DO, DIN, DIP plots for Chesapeake and San Francisco Bays (Cloern, 2001).

of estuaries and coastal waters, for instance, sea grasses are nonexistent in South Carolina estuaries. It should also be noted that variables that would be monitored for management purposes might only partly overlap with the variables that would be monitored in support of research

It is important to define the variables to be measured in order to answer questions, both conceptual (i.e. what is there) and mathematical (i.e. to predict what might be there). Models might further be used to narrow the field of core variables, in addition to their use to better understand nutrient input / water body response relationships in pursuit of effective management options. The outcome of this monitoring and assessment program should be geared toward giving resource managers what they need, when they need it, to do their jobs effectively. The intent is to provide a constant data stream that can be used for the development of status, trends, and predictions for nutrient related eutrophication (Figure 8). Workshop participants developed the following core and enhanced variables for a long-term monitoring and assessment program:

Possible Core Variables Depending on Estuarine/ Coastal Water Types

1. Salinity
2. Temperature (global/regional, seasonal, climate)
3. Meteorological data
4. Water residence time
5. Turbidity, K_D
6. Chl *a**
7. Seagrass*
8. Macrophytes*
9. Benthic algae*
10. Phytoplankton*
11. Dissolved Oxygen – relative to diel variability
12. Sediment organic content
13. Dissolved nutrients (NO_3^-, NO_2^-, NH_4^+, PO_4^{3-}, Si)
14. Total nutrients (TN, TP)
15. N:P:Si ratios
16. Freshwater Flow, nutrient concentration, load
17. Seawater exchange, nutrient concentration, load
18. Anthropogenic and natural nutrient loads
19. Point sources
20. Nonpoint sources (e.g. atmospheric)

*Changes in biomass, percent composition, aereal coverage: i.e. areal coverage for phytoplankton refers to the areal extent of blooms of very high concentration of Chl *a* as in the NEEA (Bricker et al., 1999).

Figure 8. CTD deployment.

Possible Enhanced Variables Depending on Estuarine/Coastal Water Types

1. TSS
2. Depth range of macrophytes
3. HPLC pigments - Taxon specific
4. Benthic community composition. and structure
5. SOD/BOD
6. Stable Isotopes
7. Heavy metals (Ex. Fe)
8. Harmful Algal Blooms (HABs)

Other Important Variables and Rates

1. Fish stocks
2. Land use
3. Population changes
4. Sediment fluxes
5. Internal nutrient cycling

It is very important to consider that the minimum temporal and spatial resolution necessary for characterization is dependent on typology. Depending upon the type of system and variables being measured, sampling frequency could vary through the year with highest frequency during the growing season and lowest frequency during the low-growth season. Quality control in data acquisition and processing should be assured and encouraged.

Participants agreed that it was likely that thresholds for measured variables, marking the levels above which water quality is considered undesirable, will be different for different types of estuaries and coastal systems, and the scales (i.e. high, medium, low) will require normalization for synthesis of the regional and national pictures, e.g. through the use of rating curves. Determination of thresholds for different types of systems requires considerable caution in application. As an example: dissolved oxygen in the water dictates the ecology, but thresholds set in absolute concentration may differ widely between regions depending on local (particularly temperature) conditions. For example, two widely differing values between the northern U.S. and the Gulf of Mexico may actually correspond to an identical value in percentage saturation.

It is also important to note that some parameters, such as harmful algal blooms, are not always amenable to management. While some blooms within estuarine systems are triggered by nutrients, others are not. This occurs, for instance, in parts of the U.S. Pacific, Gulf of Mexico, and North Atlantic coasts with the formation of toxic algal blooms in offshore frontal systems, which are then advected into estuarine areas. In addition, the link between toxic algal forms and nutrients is not always well established.

Socioeconomic Impacts to Human Uses

This component of the assessment is intended to evaluate the impact of nutrient related water quality problems on various human uses of the water bodies. This was not explored thoroughly in the NEEA and is the least developed of all the assessment components. Workshop participants agreed that the design of an economic analysis of the linkage between nutrient pollution effects and uses of estuaries and coastal waters was beyond the scope of their expertise. It was recognized that development of socioeconomic models of the impacts of human related eutrophication would be a significant addition to the assessment update. A recommendation was made that additional social scientists and economists with experience in economic impact analysis linking water quality and human use impairments be invited to participate in development of this component.

<u>Recommendations</u>

- Convene a sub-group of the workshop participants, some from the "Typology" sub-group, to proceed with selection of core and enhanced variables for the different types. This group should also address spatial and temporal sampling considerations, such as segmentation of estuarine/coastal water types by salinity or some other basis, and how to combine data for different segments. Determination of reference values, as well as thresholds for category ranges, methods for combining variable data into an overall score, and other methods, should also be developed by this sub-group. The assessment results should be comparable on a national basis.

- Convene a sub-group from members of the "Typology" and "Monitoring, Assessment and Classification" sub-groups to develop nutrient input/water body response (and other) models that address and inform management options. Model development will draw from results of the "Typology" and "Monitoring, Assessment, and Classification" subgroups.

- Use 3-4 core variables that are measured in all types, and additional (enhanced) variables that are tailored to specific types of systems to get an accurate characterization of conditions. The core parameter set will be identical for all types when dealing with a particular issue, although there may be additional enhanced parameters for systems within a specific type to more accurately characterize conditions for systems within that type.

- Support research for variables that show promise as indicators but need more research to link pressure to response and use new probes (e.g., new nitrate sensors, optical sensors, chlorophyll probes, etc.). Use new technologies (e.g., meters and probes) as they become available to obtain data of concern. Incorporation of new technologies should begin at the auxiliary level and not as primary methods. Work with EPA on changing methods of data collection to gain acceptance/approval for regulatory purposes.

- Use a suite of variables that is manageable. These should be used to develop indicators for characterization of status and for "early warning" of impending problems.

- Convene a sub-group composed of workshop participants, social scientists, and economists who have experience in economic impact analysis to develop an approach for determining what society's uses of systems are and methods for linking nutrient related water quality impacts to changes in those uses and their socioeconomic costs.

- Use sediment cores to determine past trends in order to find variables that have influenced conditions in the past and to provide an historical framework for interpretation of present and possible future conditions.

- Assure quality control in data acquisition and processing, both within a system and between systems, types, and regions. Pooling data is a huge asset to this kind of project and should be encouraged.

Modeling and Management of Eutrophication

The results of the "Typology" and "Monitoring, assessment and classification" groups should be used to develop models to better understand the response of different types of water bodies to varying nutrient input levels. These models can then instruct and guide development of appropriate management alternatives for different systems dependent upon type and level of impairment. In addition, model scenarios should be used to predict what might occur with changes in loadings (Figure 9). These models and results should be provided to managers for optimization of adaptive management success.

Proper adaptive management of eutrophication has to implement effective abatement measures, and also to fulfill the following two general objectives:

1) Translation and integration of science into information and tools that are useful to managers.
2) Reporting of results to the public and to Congress to leverage action (i.e. changes in legislative mandates) and funding for management and related research.

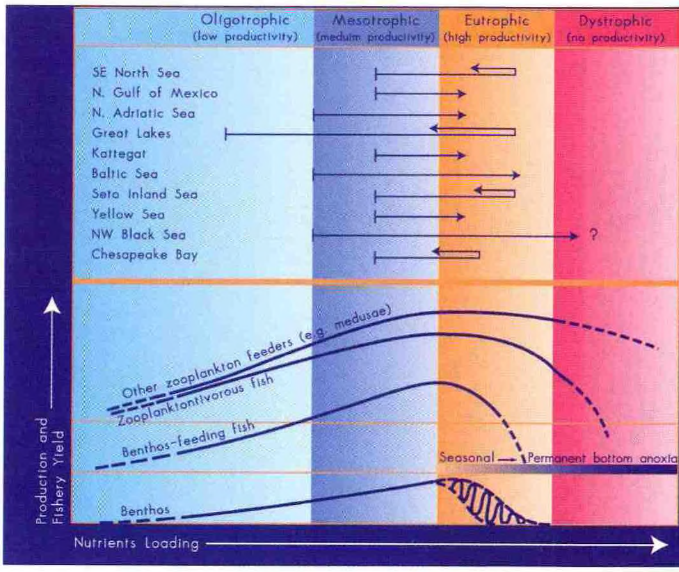

Figure 9. Comparative evaluation of fishery response to nutrient loads in the Gulf of Mexico (CENR, 2000).

Communication between managers and researchers about research and monitoring results is critical to appropriate and successful management, however, it is not sufficiently developed at present. Managers need data and information on specific time and spatial scales in order to manage resources appropriately. For example, states typically get blocks of data for a 5 year time period, which matches the life span of permits but is not useful for analyzing episodic and/or brief events such as algal blooms. Sometimes, long-term data are necessary for understanding short-term events and natural variability within a system.

Managers must articulate to the scientists what they need and when they need it. Scientists, in turn, must provide data and results in forms that are useful to managers. This might take the form of an "Operational Oceanography" interface between scientists and managers but the interface needs to be developed. This interface represents a continuous collection of data that can be used at any time to assess the status and trends in nutrient related problems, and uses historical and current data to make predictions, similar to the methods the weather service uses for forecasts.

Scientists should help managers by outlining what monitoring and research is being done and how that can help them to manage. Screening models and other analytical tools should be developed for identifying susceptibility to nutrients, including what variables must be monitored (and on what time scales) to detect changes in the system and when the system is above the threshold of desirable conditions. For example, a simple web-based screening template or tool could allow resource managers to easily determine the approximate status of an estuary or coastal water. Once the types of estuaries are described and referenced as well as threshold values of concern identified for each type, an on-line program could be set up so that a manager could:

1. Enter the estuary/coastal water body type (e.g., shallow, river dominated, coastal etc.), which would then bring up the appropriate variables associated with monitoring in that type of system. The manager could then enter measured values for those variables.

2. Threshold levels for that type of system would then be compared to the measured values. Variables above the threshold would be flagged.

3. Depending on the combination of variables found to be above threshold levels, the web-based tool would be able to provide the overall status of the water body and recommend appropriate levels of action. In cases where there are a limited number of systems within a type, the program could be preloaded with typological data (retention time, fresh water inflow, etc) for individual systems making the characterizations more accurate.

The web-tool output could also provide information on how the system was coded by the original NEEA and provide a summary of the data (i.e. number of records, range, median, mean, etc). The output should also be put into a comparative regional and national perspective which can be used to set priorities for funding.

Improved public outreach is necessary to convey information on nutrient related eutrophication impacts and success of management efforts in such a way that they are meaningful to the public. These efforts should include development of the linkage between the impacts of nutrients in an estuary/coastal water and society's uses of these waters. Impact valuations are key and necessary to convince the public and legislature to support research and management efforts. As an example, in Sarasota Bay, the mayor and city council were much more enthusiastic about creating habitat that might support 300 million additional fish, though small, than they were about secchi disk depths increasing by 25 % and seagrass meadows increasing by 700 acres. This demonstrates how this approach will serve to develop public support for management.

Recommendations

- Develop an organizing framework for states' managers, that includes a translation mechanism from the science to the managers that should include: descriptions of the susceptibility of systems to nutrients, the indicators that should be monitored to understand the direction and magnitude of change in water quality, and the thresholds that prompt policy and management changes.

- Develop an operational observation system that routinely provides data and information to managers on appropriate time frames and in the most useful format. Use the idea of "Operational Oceanography" interface between scientists and managers.

- Develop models and analytical tools for management purposes.

- Identify a Steering Group to guide further development of the monitoring and assessment program.

- Determine sub-group membership for "Typology" and "Monitoring, assessment and classification" (including reference conditions and classification issues, such as variable thresholds), "Modeling and Management" (for development of an operational framework and analytical tools) and write the scope-of-work for the groups. Overlap among groups is key.

- Identify and contact appropriate economists and social scientists for participation and guidance on development of the economic impacts/society's uses component.

- Compile a summary of data in preparation for selection of candidate estuaries for a pilot study (include search for models of susceptibility and input/response, such as that for Tampa Bay).

- Begin designing pilot studies.

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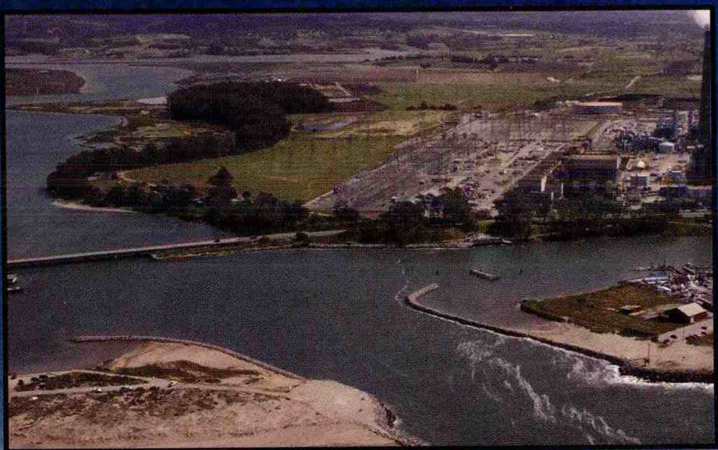

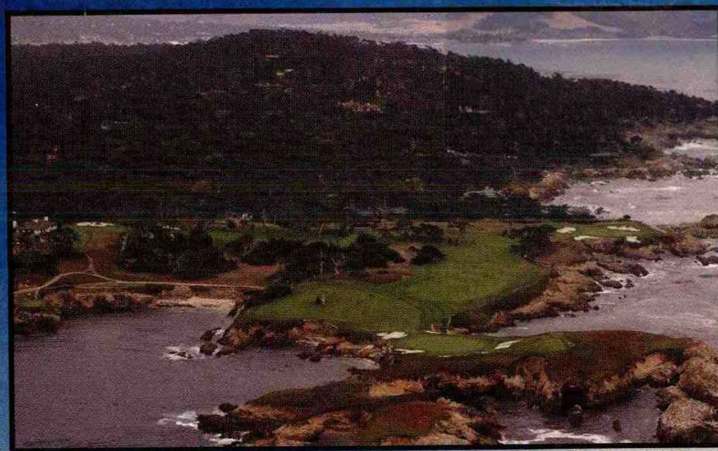

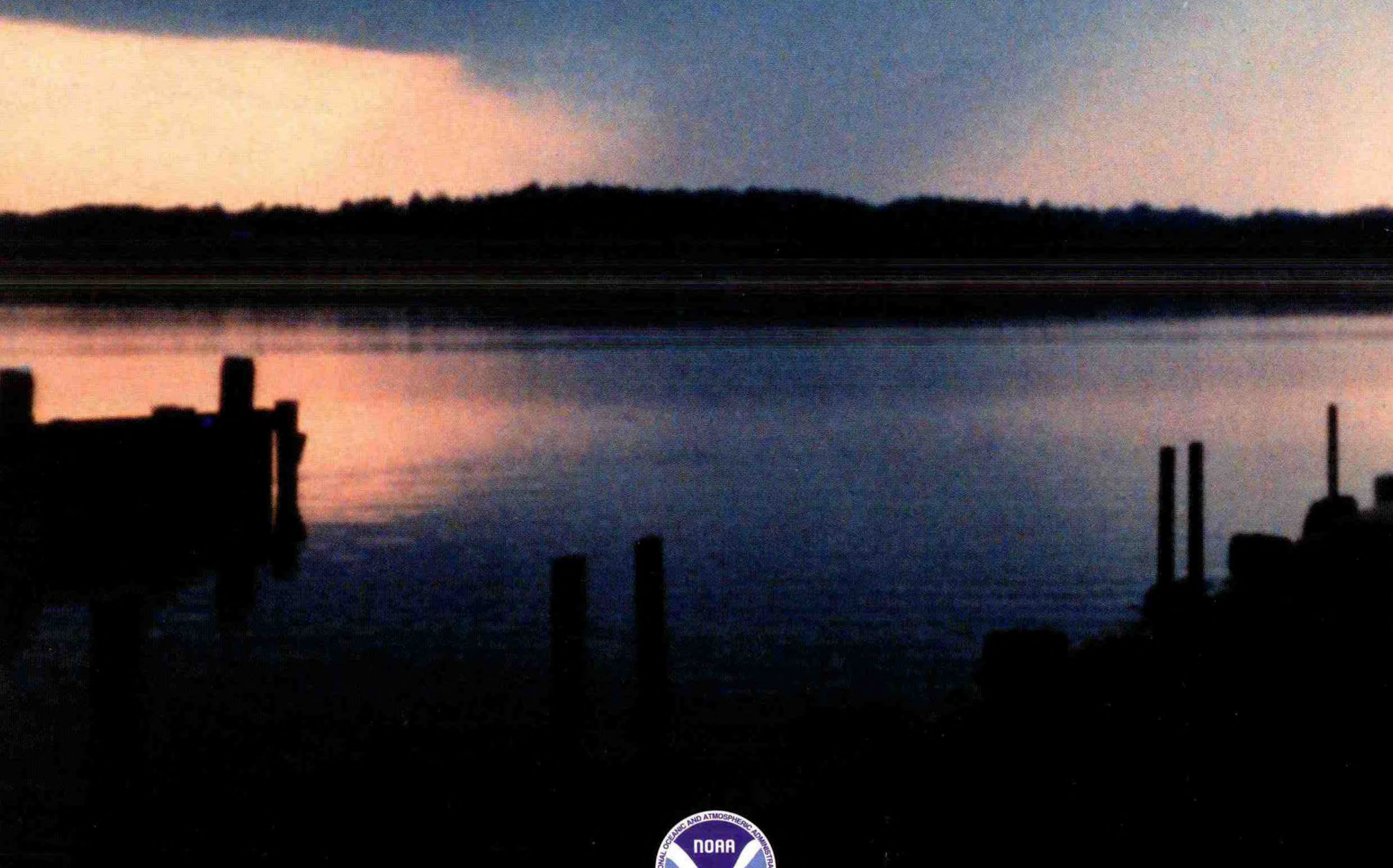

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