NATIONAL HARMFUL ALGAL BLOOM RESEARCH AND MONITORING STRATEGY:

An Initial Focus on *Pfiesteria*, Fish Lesions, Fish Kills and Public Health

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MONITORING STRATEGY:

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EXECUTIVE SUMMARY

In response to fish lesions, kills, *Pfiesteria*-like organisms, and possible threats to public health in the Mid-Atlantic region, the White House asked Federal agencies to develop and coordinate a long-term, national strategy for Federally-supported research and monitoring on problems associated with harmful algal blooms (HABs), particularly *Pfiesteria* and *Pfiesteria*-like species.

There is growing concern that the crisis in the mid-Atlantic is another of the increasing number of harmful bloom events that have become a problem in U.S. coastal waters. In previous work, scientists critically reviewed the problem and developed a national plan to monitor, assess, control, and mitigate impacts from HABs. This current strategy builds upon an existing Federal plan outlined in the report, "**Marine Biotoxins and Harmful Algae: A National Plan**"(Anderson et al. 1993), and eight focused objectives that are identified below.

To protect human health and the environment, immediate support is needed to:

o Isolate, identify, and characterize the microorganisms and their toxins;

o Develop assays for detection of cells and toxins and improved capabilities for morphological identification and enumeration;

o Better understand the impact of the organisms and their toxins on human health, marine ecosystems, and the economies of coastal areas; and

o Ensure the flow of timely, accurate, and consistent information concerning HAB events to local managers, professionals, and the general public.

To ensure that responsible agencies can respond rapidly and if necessary, implement effective management and mitigation measures, capabilities need to be in place to:

o Enable Federal and state agencies to respond rapidly through better support for monitoring, research, and assessment during *Pfiesteria* and other HAB events; and

o Maintain and update data bases and information relevant to *Pfiesteria* and other HAB events that are easily accessible, reliable and accurate.

To support management and mitigation efforts, research must also begin immediately to:

o Develop capabilities to identify systems potentially supporting *Pfiesteria*, related species, and HABs through integration of the organism's ecology and physiology with ambient environmental conditions;

o Explore new and existing technological means to prevent, control, or mitigate *Pfiesteria*, related organisms, and other HAB species, such as improving farm and watershed-scale Best Management Practices to reduce or eliminate movement of nutrients, sediments, pathogens, trace elements, and other specific organic compounds to surface and ground water.

Efforts coordinated under this strategy will complement and augment, as appropriate, state programs, and be implemented through a mix of in-house research and monitoring and research grants to universities and the states.

As an immediate response to toxic events, we expect to provide a rapid response capability for toxic events, toxin identification and assays for at least two *Pfiesteria* strains, and promote increased public awareness and education. Over the next few years, we expect to develop adequate case histories and epidemiological surveys to identify symptoms associated with exposure to *Pfiesteria* and its related species, develop diagnostics for public exposure to these events, and make progress in identifying modes of action of toxins, treatments, and therapies. More detailed characterizations of the toxins will permit development of assays for seafood and biomarkers for marine resources and humans.

Over the long-term, research characterizing watershed land use, surface and groundwater flows, chemical loadings, and water quality can be linked with an improved understanding of growth, ecology, and toxicity of *Pfiesteria* and its related species. Through an integrated, multi-disciplinary program of research, the National Strategy will provide three classes of critical information 1) characterization of environmental conditions likely to support the toxic species; 2) predictions of the onset of conditions conducive to bloom formation, and 3) means to prevent, control, or mitigate their impacts.

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INTRODUCTION

Harmful algal blooms (HABs), including highly toxic species, have increased in frequency, intensity, and severity in U.S. coastal areas over the past several decades. Recent outbreaks of fish lesions and fish kills linked to *Pfiesteria* or related species in the estuaries of the Mid- and South Atlantic States, as well as red tides and fish kills off the Texas coast, are the most recent and visible examples of this growing threat to U.S. coastal resources, coastal economies, and public health. Fortunately, as a result of significant planning over the past 5 years, the U.S. research and monitoring communities are well-positioned to address these concerns and those from likely HAB events in the future.

Harmful algal blooms were formally identified as a national concern in the 1993 report, "**Marine Biotoxins and Harmful Algae: A National Plan**" (Anderson et al. 1993). This report, produced by research scientists and agency representatives, provides a comprehensive research agenda required to adequately manage HAB species in U.S. coastal waters, and serves as the template for a national program to address impacts of *Pfiesteria* and *Pfiesteria*-related species.

Anderson et al. (1993) identify eight specific objectives that must be addressed to comprehensively evaluate, model, and manage HABs and their impacts. In the following sections, we develop a *Pfiesteria*-specific action agenda within the framework of those important objectives. Fortunately, some portions of the National Plan are being implemented through existing interagency programs. For example, ECOHAB, a new interagency (NOAA, NSF, EPA) program, is based on the community-consensus report, "**ECOHAB. The Ecology and Oceanography of Harmful Algal Blooms, A National Research Agenda**" (Anderson 1995). This program was established in FY 1997 to respond to several of the objectives outlined in Anderson et al. (1993), those specifically focused on the ecology and oceanography of HABs. The program is designed to provide information on the linkages between environmental conditions that regulate the growth and population dynamics of several harmful species. ECOHAB is expected to contribute to the development of predictive models that could be used to forecast bloom events. Nine projects currently funded in ECOHAB provide critically needed information on several U.S. coastal HAB species including toxic *Gymnodinium breve*, *Alexandrium tamarense*, *Aureococcus anophagefferens* and *Pseudo-nitzschia* species. This program could be easily expanded to address the ecology and oceanography of other HABs, including *Pfiesteria* and its related taxa.

Most recently, other objectives of the National Plan were reviewed and further developed in the report, "**Harmful Algal Blooms in Coastal Waters: Options for Prevention, Control, and Mitigation**" (Boesch et al. 1997). The report, developed by a panel of HAB experts including scientists, managers, and affected private-sector parties, outlines specific management strategies for HABs and can be used as the template for much-needed research to develop tools, methodologies, and techniques for reducing or eliminating the impacts of these blooms. While the report did not address *Pfiesteria* directly, the tools and techniques that were outlined are clearly applicable.

Boesch et al. (1997) indicated that reductions of excess nutrients in many coastal waters could well reduce some HABs. Thus, it is appropriate for a national research and monitoring strategy to consider all sources of excess nutrients and compounds which may be contributing to the enrichment of the nation's watersheds, potentially leading to outbreaks of HABs. This would include those impacted by management practices for the agricultural community, as well as non-point sources from urban, suburban and atmospheric deposition. While it has not been clearly established that substances from agriculture and other sources (inorganic and organic nutrients, trace constituents of feed, etc.) are responsible for outbreaks of *Pfiesteria* and other HABs, there is growing scientific consensus that agriculture-based materials could be a contributing factor. Therefore, there is a critical need to better understand, and develop improved strategies for management of non-point source loadings.

It is clear that the U.S. has a well-developed national HAB research and monitoring plan, as well as implementation strategies for portions of that plan. We are therefore well positioned to develop specific action plans, like this one for *Pfiesteria*-related species, as well as for new species and crises that might

impact other regions of the country.

Recent National Response - An example of a needed capability

Anderson et al. (1993) determined that a national rapid response capability was needed to address growing concerns from the threat of HABs in coastal waters, and consistent with this approach, the recent events in the Chesapeake Bay resulted in a strong Federal-state coordinated response effort to assure public and environmental health safety. The seriousness of these recent events elicited an immediate Federal and state program where combined resources were focused on monitoring environmental conditions and assessing immediate watershed land use and loadings as potential contributing factors for fish lesions and kills in Maryland's Eastern Shore region. More importantly, public health and seafood safety teams were mobilized to ensure public safety, document potential illnesses associated with the events, and assay seafood for toxicity.

The rapid response team provided: 1) intensive and frequent assays of water quality, fish lesion and mortality abundances, and pathological examination of lesions; 2) medical diagnoses and epidemiology; 3) detailed assessments of watershed loads and land-use; 4) critical review of nutrient management strategies; 5) evaluation of local case histories for those exposed to impacted waters; and 6) development of symptomologies critical for diagnosis, therapeutics, and recovery of exposed populations. It is evident that this rapid response capability must be maintained for a national response to HABs.

Despite the success of this Federal-state coordinated response, it was necessarily *ad hoc* such that, other than for direct public health response, full implementation of the objectives of Anderson et al. (1993) has not been achieved. That is, no formal mechanism currently exists to efficiently focus Federal and state capabilities . An appropriate response is given below under Objective 6.

FISH LESIONS, FISH KILLS, AND *PFIESTERIA*-LIKE TOXICITIES: RESEARCH, MONITORING, AND A RAPID RESPONSE CAPABILITY

As discussed above and specifically outlined in Anderson et al. (1993), previous experience with HABs indicates that immediate monitoring and assessment of an event is but the first step in a longer process needed to effectively control and manage resource damage and threats to public health resulting from the growth and development of potentially toxic algae and other toxic microorganisms. We must also collect and analyze appropriate new or existing data to: 1) define conditions favoring these outbreaks; 2) minimize conditions favoring future events; and/or 3) implement mitigation strategies to protect the health of coastal human populations and the natural biota of these regions.

Because of the success of Federal responses to the events in Maryland, a similar response is planned with current resources to ensure that similar successes are possible for future events. To maintain this national response capability, the following are required: 1) continued interagency discussions to ensure coordination of Federal activities specific for future response efforts; 2) continued interagency discussions on the appropriate means to formalize Federal-state assistance in the future, including designing implementation plans for Federal-state rapid response, monitoring and assessment capabilities for future events; 3) expanded discussions for increased fiscal flexibility for diverting existing resources to unexpected "crises" that will likely occur in the future, to prevent unnecessary delays in response and drastic abbreviation of existing programs; and 4) enhanced coordination of Federal outreach and communication activities for subsequent HABs in coastal U.S. waters.

Our recent experience clearly shows us that we need a more pro-active, coordinated effort for dealing with these increasingly frequent HAB events. This effort is outlined below as a national research and monitoring strategy to assess, prevent, and mitigate the impacts of fish lesions, fish kills, and threats to public safety from *Pfiesteria* and *Pfiesteria*-like organisms and other toxic aquatic organisms in estuaries and coastal waters of the U.S. Here, we focus on the *Pfiesteria* complex. Strategies for other HABs are also needed to protect public safety and fisheries resources nationwide, and subsequently may be developed.

TIME FRAMES AND FEDERAL-STATE RESPONSIBILITIES

The strategy has three key elements which are expected to yield results and products immediately, within 1-2 years, and after more than two years, respectively. To better monitor performance and results, annual assessments will report progress for each of the elements. The first element, the rapid response capability, provides individual states with Federal support and Federal expertise to immediately respond to field events and associated medical concerns. This immediate response would persist for the duration of the event and illnesses. Another aspect of this element, developing outreach programs to immediately distribute this collected information to generate real-time advisories for the public, research, and health communities, would be implemented within one year. The second element of the strategy, the monitoring and assessment partnership between Federal and state agencies, would begin immediately and continue to document conditions during and after each event to observe natural and human-derived changes in controlling factors for the toxic species. Conceivably, this could persist for 1-2 years and perhaps longer for more severe events. The third element, research, would begin immediately, largely through activities in Federal laboratories, academic institutions, and the private sector. Those programs addressing toxins, cells, and their identification and detection would likely provide results after 1-2 years for the two current toxins and species. But with the number of identified *Pfiesteria*-like organisms increasing, longer term support will be required to identify, characterize, and develop assays for additional toxins, life stages, and populations. Identification of routes of exposure, modes of actions, thresholds for response, and subsequent treatments will also begin immediately but results would likely require several years or more of continuous support. Case history data sets would be compiled within 1-2 years, but require continuous updating through time.

Research on environmental factors favoring growth and toxicity of *Pfiesteria*-like populations also requires a long-term commitment to achieve measurable results in controlling and mitigating the impacts of *Pfiesteria* and other HABs. For example, watershed characteristics, including assessments of land use activities, flows of surface and groundwater, and loadings of nutrients, organic residues, pathogens, veterinary supplements, and trace elements, would begin immediately and could require several years to compile and evaluate these observations. Linkage of these watershed attributes to the ecology, oceanography, and toxicity of the toxic organisms is a critical step, and could yield results for 3-5 years. Certain modifications (i.e., over wintering crops, wetland conservation and re-establishment) to land use practices have the potential to reduce the occurrence of toxic events in our coastal waters. The identification and evaluation of those practices that effectively manage watershed inputs that result in the redirection or elimination of substances potentially important in outbreaks of *Pfiesteria* could require several years. These assessments of system 'recovery' from practices contributing to the occurrence of toxic *Pfiesteria* outbreaks will require complex integration of ecosystem characteristics, toxic species abundances and fish distributions. Long range planning for research within the Federal agencies, academic institutions, and private industry will be required. It is readily apparent that no 'quick-fix' solutions are available.

National Strategy: Research and Monitoring Objectives

The following section provides a research and monitoring approach to address the recently observed incidents of *Pfiesteria*-related species and fish lesions and kills in the Mid- and South Atlantic coastal area. Eight objectives from the National Plan (Anderson et al. 1993) have been modified to address the specific actions required to overcome a range of impediments to prediction, mitigation, and control of crises like the recent events and for HABs, in general, in coastal regions of the U.S.

Objective 1. Isolate toxins and their natural derivatives and characterize their chemical structures and pharmacological action.

The need - To determine dose-response relationships in fish, shellfish, and humans, as well as to identify the modes of action of the toxins on animals, we must identify, isolate, and characterize toxins associated with HABs in U.S. waters.

Current efforts - There is extensive, on-going research on HAB biotoxins at a number of research institutions throughout the U.S. and worldwide. The compounds responsible for illness and death in marine biota, birds, and mammals have been identified and characterized for paralytic shellfish poisoning (PSP, saxitoxins and its congeners), neurotoxic shellfish poisoning (NSP, brevetoxins), diarrhetic shellfish poisoning (DSP, okadaic acid), amnesiac shellfish poisoning (ASP, domoic acid) and ciguatera fish poisoning (CFP, ciguatera). Research continues to explore intracellular mechanisms of action for each of these compounds. However, research has just begun on compounds produced by *Pfiesteria*-like species. Through collaborative research efforts between NOAA and NIEHS scientists and researchers at North Carolina State University and the University of Miami, significant progress has been made towards characterizing individual toxins produced by several strains of *Pfiesteria*. A fat-soluble dermonecrotic compound, likely responsible for skin lesions and epidermal damage in fish, has been isolated from one NC toxic species. At the same time, a water soluble fraction with neurotoxin-like properties has been obtained from a second fish-killing species isolated from the same area.

Required new effort - The isolation, identification, and characterization of toxins from some of the *Pfiesteria*-like species appears possible in the very near future. However, there are currently a suite of *Pfiesteria* species and related dinoflagellates that resemble each other and may also produce toxins. To identify toxins and develop modes of action for the compounds, it is critical to develop unialgal cultures of each taxon so that toxins produced can be associated with specific types of a harmful species. After establishing unialgal clones (with and without associated bacterial assemblages), it is critical: 1) to isolate, identify, and characterize the toxins produced from each strain; and 2) to determine life cycles and toxicities of life stages for each isolated strain to further characterize *Pfiesteria* and its related species. These goals and objectives can be accomplished through Federal coordination of an integrated program that includes focused Federal intramural and extramural programs.

Objective 2. Develop specific detection methods based on the unique chemistry and/or pharmacology of individual toxins and cell characteristics.

The need - Identification of *Pfiesteria*, other HAB species, and their associated toxins often occurs far from the field event (i.e., in a laboratory, days to weeks after the event), hindering government response to ensure immediate protection of public health. Quick, inexpensive, and accurate methods and standards are critically needed for field identification of toxins and HAB populations. Similarly, rapid assessments of fish health are also essential for immediate response to public concern for safe seafood.

Current efforts - Development of specific assays for the major HAB toxins and their algal sources has been on-going over the last decade. Assays for some toxins and molecular probes for several HAB species are now available. However, only recently has development of detection methods for *Pfiesteria*-like cells and their toxins begun. Assays for identifying the two toxins isolated from *Pfiesteria* strains should soon be available and the development of cell-specific probes for several strains is in progress. In addition to these developments, there are also intensive efforts within FDA to identify and characterize toxins and to provide for rapid verification of seafood safety in shellfish and fish designated for public consumption.

Required new effort - Current efforts to characterize toxic fractions (Objective 1) and to develop specific toxin assays in several *Pfiesteria* and *Pfiesteria*-like strains must be intensified, expedited, and corroborated through inter-laboratory comparisons. There are at least four strains of *Pfiesteria*-like cells that have the potential to produce a suite of water- and fat-soluble toxins. The cells will likely have differing surface characteristics and genome composition, requiring that research be expanded for detection of all toxins, toxic strains (cell-specific probes for surface characteristics or alternatively, cellular genomes) and toxic life stages. These activities are entirely dependent upon obtaining unialgal cultures, previously identified as a high priority in (Objective 1 above). The subsequent development of detection capabilities requires sophisticated molecular technologies, including genetic markers, molecular probes, and bio-optical sensors. Further, biomarkers indicative of toxin exposure must be identified for all biota (including humans). There is also a need to develop and apply immunological methods to detect

and monitor antibodies and antigens in affected fish.

Objective 3. Determine the source, fate, consequences, and potential impacts of dinoflagellate toxins in the ecosystem and on human health.

The need - Although identified as a major need in the National Plan (Anderson et al. 1993), little is known about the potential impacts of HAB toxins on coastal food webs, ecosystems, and humans. To ensure adequate protection, prevention, control, and mitigation of *Pfiesteria* and other related toxic HAB organisms, we must identify and understand the critical pathways of exposure potentially affecting living marine resources and humans. Two of these paths of exposure to humans are transfer of HAB toxins through coastal marine food webs and direct contact.

There is some information on the effects of several toxins on individual trophic levels (e.g., NSP in manatees, PSP in zooplankton and fish) but in general, there are few studies on transfer and impacts of toxins from one trophic level to another. Impacts on top consumers are often only visible after the fact (e.g., death of marine mammals and birds or as illness in human populations in coastal areas). Most importantly, there is a critical lack of knowledge about the potential impact of chronic (i.e., sustained, sublethal) exposures to toxins. Further, as there are multiple causes of lesions in fish, we must also develop the ability to distinguish among multiple causal factors contributing to fish health problems, separating toxic organism effects from other factors.

Current efforts - The transfer, fate, and impacts of toxins on marine food webs, ecosystems, and humans is, though critically important, poorly addressed in current Federal agencies' activities. Federally-sponsored research in this area is limited and focused on the fate and effects of toxins from toxic *Pfiesteria*-like species on other components of the estuarine/marine ecosystem. Some collaborative research between USDA and Maryland's Center of Marine Biotechnology will target residence times and clearance rates of *Pfiesteria* toxins from fish tissue. This is important, not only from the perspective of seafood safety, but also from the perspective of the possible transfer of toxins to livestock in toxin-rich fish meal feed. Toxin accumulation in animals feeding on *Pfiesteria* and other aquatic organisms which feed on it are also a priority of FDA's Office of Seafood. Fish health is also a concern, and there are a few investigations of fish health linkages to HABs as in recent EPA and NOAA-Maryland histopathological evaluations of fish from *Pfiesteria*-related kills and surrounding areas.

Research evaluating human health effects has just begun. Preliminary health assessments of exposed populations in Maryland have been initiated by Maryland-Federal (CDC, NIEHS) medical assessment teams. Follow-up epidemiological studies will be initiated in 1998. Animal studies, to determine dose relationships to toxins and to investigate inhalation toxicology of a *Pfiesteria* strain, have recently been funded through NIEHS. Additional efforts, by NOAA and EPA, will examine effects on the central nervous system and will include histological examinations of various organs and tissues from model populations. Findings will be correlated with human health outcomes.

Required new efforts - There is a critical need to identify and characterize biochemical components in fish secreta suspected in triggering ("inducing") toxin production in *Pfiesteria* and the related species. After a decade of work examining factors for control and regulation, toxin induction still remains a mystery. Identification of the triggering substance(s) and threshold levels for the substance(s) must be determined. Additionally, it is critical that factors inducing production of dermonecrotic compounds versus neurotoxins in the *Pfiesteria*-like populations be identified.

The results of this type of information are needed for public health advisories (states, NIEHS, CDC, EPA), as well as to ensure public confidence in the safety of seafood (FDA). Additional research is required on human and natural resource responses to detect toxin exposure and on potential impacts of toxins on the marine food web and coastal ecosystems. This strategic approach places high priority on the acceleration of epidemiological assessments of direct effects on human health. These assessments

must include identification of toxin exposure routes, mechanisms of action, thresholds for biotoxin effects, levels of tolerance in marine animals and humans, and mechanisms of susceptibility. Critical to these endeavors is the validation of detection methods for biological fluids, the development of exposure biomarkers in humans and in coastal biota, and conducting epidemiological surveys in areas subject to toxic HABs. Toxin accumulation and persistence in seafood must also be emphasized in expanded research efforts at the FDA.

The impact of HABs on coastal ecological systems must be better understood. In response to the current crisis over the long term, it is important to expand research to include all species and life stages of taxa related to *Pfiesteria*, as recent observations indicate impacts to humans and coastal marine resources extend beyond the most studied species, *Pfiesteria piscicida*. Due to the complexity of *Pfiesteria piscicida*'s life cycle (and similar complexity in related species) and the paucity of information on the toxicity of this and other related species, it will be impossible to address these difficult issues in a short-term research program. Therefore, with this complex array of species, strains and life stages, research on marine ecosystems focused on food web transfers and direct exposure to toxins must begin immediately and should include potential Federal trust resources (e.g., migratory birds and marine mammals).

Objective 4. Develop the ability to predict the occurrence and potential impacts of toxic outbreaks of Pfiesteria-like dinoflagellates on marine ecosystems and fish health.

The need - Successful control and mitigation of HABs and events such as those observed recently in the Chesapeake Bay depend on developing an efficient and reliable predictive capability. Developing this capability requires an understanding of the natural ecology of the HAB organism, its relationship to general environmental conditions, and the specific "event-based" processes that lead to expression of harmful toxicity, or alternatively to those conditions that are conducive to the growth of non-toxic forms of potentially harmful plankton including *Pfiesteria*.

Current efforts - Although a few models have been developed that explain observed distributions of several toxic species (e.g., coastal *Alexandrium* populations in Maine, *Gymnodinium breve* in North Carolina), it is not possible to predict the occurrence of toxic algal blooms. The complex linkages between regional circulation, physical and chemical oceanography, and the eco-physiology of each toxic species have remained unexamined due to the large costs associated with such studies. Research observations over the last few years (NOAA, EPA, and USDA sponsored projects) and results from the recent Federal-state monitoring effort in the Chesapeake Bay and Mid- and Southeastern Atlantic events have implicated some general conditions that favor toxicity from *Pfiesteria* and its related species. These suggest the following: 1) generally eutrophic conditions must prevail; 2) systems must be shallow and warm with poor circulation; and 3) fish must be present. However, relationships between these and other environmental factors regulating (or "triggering") toxicity in this or related organisms remain poorly understood not only locally but for the majority of the U.S. coastline.

Fish lesion assessments (i.e., pathology, microbiology, and histology) are continuing in the affected regions of the Chesapeake Bay system and are coordinated through the Federal-state partnership at USGS and NOAA/MD laboratories. Additional research at EPA's Office of Research and Development (ORD) is evaluating fish lesion pathology. Research to measure and predict the potential contribution and transport of agricultural nutrients to surface and ground water is currently underway at USDA, EPA, and USGS. In addition, as part of EPA's Mid-Atlantic Integrated Assessment project and a related Committee on Environment and Natural Resources (CENR) project in the mid-Atlantic area, the roles of nutrients, sediments, and other estuarine conditions are being evaluated as part of an overall assessment for the region. These efforts will likely contribute to enhancing our ability to understand HABs, including *Pfiesteria*.

Required new efforts - Although the few models that have been developed to explain observed distributions of coastal *Alexandrium* populations in Maine and *Gymnodinium breve* in North Carolina appear promising, prediction of toxicity in the natural environment for these two species nor any other is

not yet possible. Direct linkages between the environment and the physiology, ecology, and behavior of toxic organisms are incompletely understood. For example, even though there is some evidence indicating that agriculture-based nutrients and other compounds could be important contributing factors to the proliferation of one of the *Pfiesteria*-like strains, it has not been clearly established that nutrient sources or other environmental conditions (e.g., low pH, specific organic compounds and trace metals, high dissolved organic compound concentrations) are directly responsible for conditions encouraging these outbreaks. Clearly, more work is required on the nutritional requirements of *Pfiesteria*. Almost completely unknown is the impact of veterinary pharmaceuticals on aquatic communities, and specifically their role in stimulating the growth of HABs including *Pfiesteria*. Therefore, there is a critical need to understand the physiological ecology of this and other toxic species, by comparing their nutritional responses and food web interactions under defined experimental conditions with field responses under manipulated or naturally variable conditions. We must quantify all factors contributing to outbreaks of this and other toxic HAB species so as to identify specific systems where outbreaks may occur. Further, identification of critical factors limiting toxicity as well as those acute **and** chronic conditions that may be responsible for poor fish health, productivity, fecundity, and stock recruitment (toxic species vs. anoxia/hypoxia, pesticides, etc.) will permit better management of those factors contributing to toxic events.

With the recent emphasis on the potential role of agricultural inputs in initiating toxic algal events in coastal areas of the mid- and southeastern U.S., more focused research must be undertaken to develop tools and methodologies (such as remote sensing techniques) to measure and predict the fate and transport of agricultural nutrients and other materials in surface and ground water. These tools will also help to quantify the contribution of these inputs to increases in the number and frequency of outbreaks and toxicities of coastal nuisance species, including *Pfiesteria* and other related taxa. Examination of loadings from all major contributing sources, including both point and non-point sources (e.g., sewage treatment facilities, poultry, and other agricultural activities), must be undertaken to identify or eliminate specific watershed land-use practices contributing to HAB events in an effected coastal region. In support of eliminating specific land-use practices, research to improve models for TMDL (total maximum daily load) from non-point sources is necessary.

Just as important, however, is the need to determine how river, estuary, and basin characteristics (e.g., runoff, hydrology, residence time, meteorology, bathymetry) contribute to the distribution of inputs relative to the nuisance organism, and in the case of *Pfiesteria* and related species, the distribution of fish prey. For example, the addition of a site to the Delmarva National Water Quality Assessment Program site in the Pocomoke watershed would provide necessary flow data perhaps critical to event expression in the system. The suite of factors critical to population growth will then indicate those systems capable of supporting toxic *Pfiesteria* or HABs, while eliminating others, for routine monitoring *prior to* toxicity development and fish kills. This comprehensive approach, consistent with the ECOHAB model, should be vigorously pursued with short- and long-term support of competitive, peer-reviewed intra- and extramural research programs. The current ECOHAB program, jointly funded by NOAA, EPA, and NSF, provides a model for conducting the required research to identify conditions responsible for toxicity in the recent crisis on the eastern seaboard, supporting multi-disciplinary studies linking circulation, bathymetry, and physiology and ecology of several toxic species (including nutritional requirements for growth) to predict bloom expression and toxicity in coastal U.S. waters.

In addition to the integrated, multi-disciplinary research program, there are several existing Federal monitoring programs that with expansion, could substantially improve our ability to understand and narrow the number of systems supporting outbreaks of *Pfiesteria*-related species and other HABs in the Mid- and Southern Atlantic. For example, sediment cores from the region (collected by USGS), coupled with cell-specific probes for *Pfiesteria* and its related species (Objective 2), could be used to establish historical linkages between these populations and environmental conditions. In addition, EPA's National Estuary Program has also identified nutrient over-enrichment and HABs as priority problems in most of its 28 national estuaries. Data from these systems could provide the basis for developing and implementing future coastal resource management actions to limit HAB expression. Two of these

systems, the Delaware Inland Bays and the Albermarle-Pamlico Sound, are sites with fish lesions, kills, and large proliferations of *Pfiesteria*-like populations. USDA watershed programs to identify areas susceptible to nutrient losses should also be expanded, with results assisting the identification of priority targets for application of Best Management Practices to protect water quality (see Objective 5 below).

Objective 5. Apply research findings toward developing options for effective management and mitigation of HABs.

The need - While health and environmental resource protection agencies appropriately take conservative approaches (by immediately closing affected areas) to protect public safety and to protect local economies from unnecessarily restrictive or overly protective sanctions, much more needs to be done to pro-actively manage, prevent, control, and mitigate the impacts of HABs. To effectively minimize economic losses attributable to HAB mitigation options, accurate risk assessment approaches, including comparative risk assessment and economic valuation, must be incorporated in the environmental decision-making process.

Current efforts - Extensive shellfish monitoring programs are well-established in each state for PSP, NSP, DSP, and ASP toxins. There are also numerous Federal programs that document nutrient loadings to coastal systems. However, fewer programs are operating to determine trends in nutrient cycling and availability. Both the coordinated Federal-state rapid response approach for monitoring, assessment and epidemiological surveys for the Chesapeake Bay region (described above) and the recently funded EPA-North Carolina rapid response program for the Neuse River, demonstrate the value of HAB rapid response activities requested in the National Plan. Effective now that they are in place, these programs were initially reactive rather than pro-active. If continued, they can provide baseline data that can be used to: 1) identify environmental factors favoring toxic events and symptomologies of exposed populations; 2) develop diagnoses and therapies for exposure, critical to public health care providers; and 3) narrow the suite of environmental factors coincident with the HAB events. As noted above, specification of environmental conditions preceding or accompanying an HAB event can be used to identify systems with similar characteristics, thus substantially limiting the number of systems where intensive monitoring programs might be required in future mitigative strategies.

Required new efforts - The recent crisis in Maryland and Texas emphasize the immediate need to critically review available techniques for ameliorating impacts of toxic species on coastal environmental resources, local economies, and public health. Historically, reducing impacts of toxic species required the maintenance of expensive, continuous shellfish and fish monitoring programs, closures of fisheries, posting health warnings, and supporting toxin assays to determine seafood safety, all costly to local economies.

The recent report, "**Harmful Algal Blooms in Coastal Waters: Options for Prevention, Control, and Mitigation**" (Boesch et al. 1997), strongly supports a re-examination of nutrient control strategies in coastal ecosystems as these measures to reduce pollution (including excess nutrients) could yield positive results in terms of reductions of some HABs and their impacts. Results from research related to Objective 4, identifying nutrient and other inputs that support growth of *Pfiesteria* and HABs, permit management of some inputs with the potential to stimulate HAB events, thereby reducing their impacts. For example, Federal support to develop and improve basin-specific Best Management Practices (BMPs) to reduce or eliminate transport of nutrients and other chemicals to waters are important. This could include development of specific techniques for managing these inputs (such as the role of vegetation and feed-lot and manure application practices in reducing non-point source nutrients) to reduce event occurrence.

Research on the science and economics of managing animal wastes, including composting, feed composition, and ability of soils to retain phosphorus, is also needed. Several specific examples of programs that might be expanded include EPA's assessment of loadings from animal feed operations through the permitting process of the National Pollution Discharge Elimination System, using field

collected monitoring data for establishing inputs and limits. USDA research programs to develop BMPs to reduce or eliminate movement of nutrients, pathogens, sediments, and agricultural chemicals to surface and groundwater might also be enlarged. These could lead to development of methods and practices to reduce nutrient losses to the environment during handling, storage, and field application of manures. The control of air deposition of nutrients or other chemicals that may facilitate outbreaks of *Pfiesteria* or HABs should also be intensively examined (EPA, NOAA Programs) as there is increasing evidence that air-borne materials can dramatically alter water quality and productivity of receiving waters. With the array of toxic species, coastal systems and watershed uses in the U.S., we can expect that there will likely be unique treatment capabilities for each nuisance organism and coastal environment.

In addition to control of watershed inputs (e.g., nutrients, organics, food supplements, sediments, pesticides, herbicides, etc.), there are several other areas that will likely increase our ability to reduce harmful events and their impacts. These include 1) formal development of health care responses for individuals exposed to HAB toxins and 2) accurate risk assessment studies that contain economic evaluation as a key element. The first effort would include adoption of standardized medical examinations and testing procedures toward generation of comparable data sets across jurisdictions, ultimately reducing public illness and health expenses. The second effort would provide potentially useful measures for estimating bloom impacts and benefits of controlling the harmful events.

Objective 6. Provide for rapid response to, and long-term monitoring of, toxic and otherwise harmful marine algal outbreaks.

The need - As described above, and recommended in the National Plan, rapid response capabilities are essential for an effective U.S. HAB program. These events currently are unpredictable, and often ephemeral, and factors contributing to their occurrence are poorly understood. A rapid response capability can provide: 1) limits on the extent of the event, thereby easing anxiety in locally impacted communities and impacts to local economies; and 2) an understanding of base conditions for bloom development or toxicity expression. To respond rapidly to an HAB event, a collaborative agency effort is needed to measure and characterize water quality, flow, and other critical environmental conditions, as well as to adequately assess biological impacts during and following an outbreak.

Current efforts - With some Federal assistance, state and local governments have most frequently responded to HAB catastrophes involving large animals inhabiting coastal ecosystems such as whales, dolphins, birds, and manatees. The recent crisis in Maryland, however, resulted in an immediate and highly effective Federal (NOAA, EPA, NIEHS, USDA, CDC)-state partnership, following a coordinated, integrated rapid response team approach. This approach expanded monitoring of water quality, plankton, fish lesions and their pathologies, and fish bioassays, as well as measures of ambient toxicity and watershed inputs. In addition, USGS re-examined watershed loadings for impacted areas. Federal agencies also provided immediate assistance to Maryland in medical identification and epidemiology. This rapid response approach resulted in immediate sampling and data analysis in support of critical real-time management decisions (e.g., river closures, advisories) and provided an event-focused, medical analysis of river-induced illness of local users. This effort proved invaluable to easing regional concerns about the events. In addition, EPA is currently funding North Carolina to develop a similar rapid response plan, built around an extensive monitoring program for fish kills in the Lower Neuse River estuary.

Required new efforts - Federal agencies have the skills and equipment to assist states in rapid response monitoring and assessment activities. Because of the increasingly frequent appearance of harmful algae in our nation's coastal waters, a specific set of Federal resources, technical skills, and response strategies must be maintained and supported, to prepare an interagency rapid response team for future events. Additional Federal assistance to state monitoring programs will be necessary to enhance both long-term and event monitoring (including identifications of harmful species) and assessment capabilities. Through enhanced support to FDA, further development of the field observer network will increase our rapid response capability.

Objective 7. Develop information, communication, educational, and public health materials and on-site training strategies.

The need - While some HABs have been occurring in coastal waters for years, others (such as *Pfiesteria*-like populations in the Mid- and Southeastern U.S.) are new and novel. In many cases, resource and human health managers, as well as the general public, are unfamiliar with symptoms of toxin exposure, and are often not prepared to respond rapidly and effectively in crisis situations. It is essential that we provide current and accurate information, for both professionals and the public, to minimize unfounded public and local government fears and to assist in near-time critical environmental resource management decision making.

Current efforts - Outreach (e.g., web sites, newsletters, and fact sheets), specific to events in the Chesapeake and North Carolina, is an integral part of on-going activities within NOAA, EPA, USDA, and NIEHS. For example, NIEHS has specific guidelines for its Center Program, requiring immediate distribution of research results to research and medical communities. To identify research needs and to address important issues, NIEHS, CDC, USDA, and EPA have also recently held workshops to evaluate the state of the science associated with *Pfiesteria*, its related species, and other toxic HAB species, and to evaluate the threat of HABS to human health and natural ecosystems. In addition, the National Office for Marine Biotoxins and Harmful Algal Blooms (funded by NSF and NOAA) at the Woods Hole Oceanographic Institution maintains a HAB web page that contains useful information on toxin syndromes, newsworthy events, and reference material.

Required new efforts - At a minimum, strategies to strengthen outreach activities must be developed and coordinated at the Federal and state level, to ensure prompt distribution of information. The activities would minimize public and local government concerns to local HAB events, provide public health advisories, guide seafood safety advisories, and identify regional hot spots impacted by HABs. Therefore, existing communication, outreach, and education efforts should be reviewed, integrated, and made accessible across agencies to ensure an adequate flow of information and materials to agency partners/constituents and to facilitate an awareness of recent research findings. Specific needs include training of health care providers, implementing phone inquiry systems for impacted areas, and developing electronic information services (including web sites) for distributing information. Additionally, agencies should take advantage of local, regional, and national media (e.g., public television, radio) to reach the public, especially seafood consumers. Training programs for health care providers as well as for scientific personnel in sample collection, cell identification, and toxin assays must be established through state and Federal laboratories.

Objective 8. Identify and improve access to databases documenting bloom incidence, toxin occurrence in shellfish, mass mortality events, and epidemiology.

The need - Access to accurate, reliable, and quality-assured data and information is critical to assess environmental factors contributing to or coincident with HAB formation in marine ecosystems. These data also provide the basis for research programs to determine impacts of HAB events on coastal resources. Epidemiological data provide case histories for those exposed to toxins (critical to identifying various routes of exposure and preventive strategies to reduce exposures and symptomologies) and for developing potentially life-saving treatments and therapies. Finally, the data are essential in publication of up-to-the-minute advisories for health care providers and the public.

Current efforts - A number of data bases are readily available covering a suite of environmental parameters (e.g., Chesapeake Bay Office, STORET, NODC, USDA land use, GULFNET, ECOHAB projects, FWS National Wild Fish Health Survey, EPA Index of Watershed Indicators, National Agriculture Library).

Required new efforts - Relevant and accurate data documenting the symptomology of *Pfiesteria*-related illnesses are currently unavailable. However, the need to fill this important information

gap is acknowledged as a national goal at both the Federal (CDC and NIEHS), and at the state (Maryland and North Carolina) level. With CDC participation, case history data will be made available. To provide more information on the status of fish health in impacted systems such as the Eastern Shore of Chesapeake Bay, data bases need to be expanded through more intensive monitoring of tidal portions of tributaries.

SUMMARY OF REQUIRED ACTIONS

From a review of Federal intramural and extramural programs, it is clear that implementing the objectives modified from the original National Plan (Anderson et al. 1993) will address the specific problems of fish lesions, fish kills, and toxicities of *Pfiesteria*-like populations observed in Mid- and South Atlantic states. The objectives summarized below identify research and monitoring areas critical for more effective response, increased understanding of effects on ecosystems and public health, and for better control and mitigation of these impacts.

To protect human health and the environment, immediate support is needed to:

o Isolate, identify, and characterize the microorganisms and their toxins;

o Develop assays for detection of cells and toxins and improved capabilities for morphological identification and enumeration;

o Better understand the impact of the organisms and their toxins on human health, marine ecosystems, and the economies of coastal areas; and

o Ensure the flow of timely, accurate, and consistent information concerning HAB events to local managers, professionals, and the general public.

To ensure that responsible agencies can respond rapidly and if necessary, implement effective management and mitigation measures, capabilities need to be in place to:

o Enable Federal and state agencies to respond rapidly through better support for monitoring, research, and assessment during *Pfiesteria* and other HAB events; and

o Maintain and update data bases and information relevant to *Pfiesteria* and other HAB events that are easily accessible, reliable, and accurate.

To support management and mitigation efforts, research must also begin immediately to:

o Develop capabilities to identify systems potentially supporting *Pfiesteria*, related species, and HABs through integration of the organism's ecology and physiology with ambient environmental conditions (hydrology, nutrient and other anthropogenic loads, and bathymetry);

o Explore new and existing technological means to prevent, control, or mitigate *Pfiesteria*, related organisms, and other HAB species, such as improving farm and watershed-scale Best Management Practices to reduce or eliminate movement of nutrients, sediments, pathogens, trace elements, and other specific organic compounds to surface and ground water.

IMPLEMENTATION STRATEGIES

While this strategy has been reviewed by representatives from the academic community, Maryland state agencies, scientific advisors to the Maryland Department of the Environment, and the *Pfiesteria* Commission (established by the Governor of Maryland), it represents the Federal response strategy for

research and monitoring. Though distinct from specific state programs and approaches, it is intended to complement and augment those efforts where appropriate.

Expertise to implement the objectives resides in the academic community and in state agencies, as well as in Federal laboratories and programs. Thus, implementation of programs coordinated under this strategy will rely on an appropriate mix of in-house and external research and monitoring programs, largely based on results of competitive, peer-review processes. **The results of these research and monitoring programs will be used in generating effective environmental policy decisions.**

EXPECTED OUTCOMES

Short-term -- These activities, in the short-term, will provide a rapid response capability for toxic events for each state through Federal support and coordination of needed Federal expertise with state field and medical teams and a Federal capability to immediately support state monitoring and assessment programs for affected areas and populations. Additionally, toxin identification is likely for at least two strains in the near future, with assays for these toxins not far behind. Characterization of other toxins and related *Pfiesteria*-like cells and development of additional assays for these new biotoxins and populations will also move forward rapidly; however, definitive results will likely not be seen for several years. Increased public awareness and education will be immediate gains with an extensive but coordinated Federal outreach program.

Intermediate -- Ensuring public health during and after toxic events is a high priority in this Strategy. At time scales of 1-2 years, case history compilation and epidemiological surveys will also permit identification of symptoms associated with exposure to *Pfiesteria* and its related species and development of diagnostics for public exposure to these events. Thereafter, in conjunction with research results on modes of action of toxins, treatments and therapies for exposure will be described. Further, detailed characterization of toxins will also permit development of toxin assays for seafood, ensuring public safety in systems where *Pfiesteria* and similar populations are found.

Longer-term -- Cataloging watershed characteristics, including land-use and characterization of anthropogenic additives, surface and groundwater flows and loads, water quality, residence times and bathymetry, will also begin immediately, yielding data sets within 1-2 years. However, linking these environmental characteristics with growth, ecology, and toxicity of *Pfiesteria* and its related populations will require a longer term commitment to an integrated, multi-disciplinary research program that includes collaboration between Federal laboratories, academic institutions, and the private sector. Results, several years in the future, will include a means to narrow the number of coastal environments likely supporting the toxic species as well as providing specific management actions in each watershed that will permit some control of toxicity in these systems.

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NOAA Coastal Ocean Program Decision Analysis Series No. 10. NOAA Coastal Ocean Office, Silver Spring, Md. 46 pp., appendix. **APPENDIX I.**

OBJECTIVES	TYPE*	AGENCY						
		EPA	NOAA	NIEHS	CDC	USDA	DOI	FDA
1. Isolate, characterize toxins								
Current Pfiesteria-related efforts								
Pfiesteria, Pritchard Pond isolate, water soluble toxin	R		X	X				
Pfiesteria, Noga isolate, lipid soluble toxin	R			X				
Identification of *Pfiesteria* toxins	R			X	X			X
Required new Pfiesteria-related efforts								
Develop/characterize each potentially toxic strain of *Pfiesteria* and the *Pfiesteria*-complex	R	X	X	X		X	X	X
Determine toxicity of each strain and begin the isolation and identification of toxins produced	R	X	X	X	X	X		X
Determine life cycles and toxicities of life stages for each isolated strain	R	X	X	X		X		X

* R - Research; M - Monitoring; O - Outreach

OBJECTIVES	TYPE*	AGENCY						
		EPA	NOAA	NIEHS	CDC	USDA	DOI	FDA
2. Detection methods								
Current Pfiesteria-related efforts								

Pfiesteria, Pritchard Pond water soluble toxin	R		X	X				X
Pfiesteria, Noga isolate, lipid soluble toxin	R			X				X
Probe development to differentiate *Pfiesteria* - like organisms	R		X	X		X		
Toxins, toxicity assays for seafood	R		X			X		X
Fish lesion pathology	M	X	X			X	X	
Required new Pfiesteria-related efforts								
Refine methods to detect toxins	R	X	X			X		X
Develop methods for field detection of *Pfiesteria*-like cells	R/M	X	X			X		X
Field test & apply cellular probes that have been under development	R/M		X			X		X
Develop biomarkers of lethal and sublethal neurotoxicity for fish and/or humans	R/M		X		X	X	X	X

* R - Research; M - Monitoring; O - Outreach

OBJECTIVES	**TYPE***	**AGENCY**						
		EPA	**NOAA**	**NIEHS**	**CDC**	**USDA**	**DOI**	**FDA**
3. Toxins in marine foodwebs, fisheries & humans								
Current Pfiesteria-related efforts								
Pfiesteria effects on fish & shellfish	R	X				X		X

Animal models, epidemiological studies, dose/response & biomarker development for humans & ecosystems	R			X	X	X		X
Medical surveys, case history development	M			X	X			X
Pfiesteria effects on human health	R		X	X	X			X
Neurobehavioral effects of dinoflagellates in rats	R		X	X				X
Required new Pfiesteria-related efforts								
Biotoxin impacts on marine organisms: Direct & indirect effects; thresholds; hazard identification methods	M/R	X	X			X	X	X
Biotoxin impacts on humans: Direct & indirect effects; thresholds	M/R	X		X				X
Biotoxins: Pathways & transformation	M	X	X	X				X
Human symptomologies & epidemiology	M				X			X

* R - Research; M - Monitoring; O - Outreach

OBJECTIVES	**TYPE***	**AGENCY**						
		EPA	**NOAA**	**NIEHS**	**CDC**	**USDA**	**DOI**	**FDA**
4. Forecasting capabilities (including ecology)								

Current Pfiesteria-related efforts								
Support State efforts to identify potential hot-spots.	M/R	X	X			X	X	
Pfiesteria, nutrient relationships	R	X	X		X			
Anthropogenic loading & *Pfiesteria*	R		X		X	X		
Pilot study linking land, water, air, biota, and people in Mid-Atlantic	M/R	X			X			
Plankton Observer Network	M						X	
EPA National Estuary Program	M/O	X						
Required new Pfiesteria-related efforts								
Determine factors causing toxic blooms: Link physics, hydrology, ecology & physiology of species	R/M	X	X		X	X		
Develop model for identifying specific systems optimal for growth	R/M/O	X	X			X	X	
Delmarva National Water Quality Assessment Program (NAWQA)	R/M					X		
Role of veterinary pharmaceuticals in bloom formation	R	X						
Plankton Observer Networks	M						X	

Develop ability to distinguish among causes of fish health problems	R/M/O	X	X			X	X	

* R - Research; M - Monitoring; O - Outreach

OBJECTIVES	TYPE*	AGENCY						
		EPA	NOAA	NIEHS	CDC	USDA	DOI	FDA
5. Develop management & mitigation options								
Current Pfiesteria-related efforts								
EPA National Nutrient Strategy	M/R	X				X		
Animal Feeding Operations	M	X				X		
EPA National Estuary Program	M/O	X						
Non-Point Source Programs	M/O	X	X			X		
Required new Pfiesteria-related efforts								
Non-point source control: Improve Animal Feeding Operations, Total Maximum Daily Load, and air deposition models	M/R	X	X			X		
Research on prevention, control & mitigation strategies, including hydrological/biological conditions	M/R		X				X	

Development of water quality criteria for nutrients	R/M	X	X			X	
Develop health care responses for human toxin exposure and risk assessment studies on bloom impacts/benefits of control	R			X			
Evaluation of economic impacts to support cost-benefit analyses of mitigation strategies	R		X				

* R - Research; M - Monitoring; O - Outreach

OBJECTIVES	**TYPE***	**AGENCY**						
		EPA	**NOAA**	**NIEHS**	**CDC**	**USDA**	**DOI**	**FDA**
6. Rapid response to HABs								
Current Pfiesteria-related efforts								
Support to States for developing and implementing rapid response plans (watershed loads, water quality, plankton, lesions, fish kills, toxicity assays)	M/R	X	X	X		X	X	X
Federal assistance to medical & health programs on *Pfiesteria* in Maryland and North Carolina	M/R			X	X			
Required new Pfiesteria-related efforts								

Providing an interagency Rapid Response Team capability for all future events in U.S. coastal waters	M	X	X	X		X	X	X
Federal assistance to state monitoring programs	M	X	X			X		X

* R - Research; M - Monitoring; O - Outreach

OBJECTIVES	**TYPE***	**AGENCY**						
		EPA	**NOAA**	**NIEHS**	**CDC**	**USDA**	**DOI**	**FDA**
7. Communication, outreach, education								
Current Pfiesteria-related efforts								
Websites, Newsletters, Fact Sheets	O	X	X			X	X	X
Workshop on *Pfiesteria* and marine toxins	O	X	X	X		X		X
Research results distributed to research and medical communities	O		X	X		X		X
Workshop: Comprehensive public health approach to *Pfiesteria*	O				X	X		X
Training workshops on isolation of *Pfiesteria* toxin, biomarker for exposure, probes	O		X	X	X	X		X
Required new Pfiesteria-related								

efforts							
Develop and implement a public outreach strategy to ensure effective dissemination and public access to information related to *Pfiesteria*, other HAB and fish kills	O	X	X				X
Develop public health advisories, guidance on seafood safety and identification of regional 'hot-spots'	O		X			X	X
Conduct conferences addressing scientific and lay communities to communicate recent research findings.	O	X	X	X		X	X

* R - Research; M - Monitoring; O - Outreach

OBJECTIVES	TYPE*	AGENCY						
		EPA	NOAA	NIEHS	CDC	USDA	DOI	FDA
8. Databases								
Current Pfiesteria-related efforts								
Federal-Maryland epidemiology	M			X	X			
NOAA-EPA Chesapeake Bay Program long-term water quality, plankton	M	X	X					
STOrage RETrieval (STORET), National Oceanographic Data Center, National Wild Fish Health	M	X	X				X	

Nutrient loads, poultry operations, conservation for Delmarva, Chesapeake and Pocomoke	M					X		
Environmental Monitoring and Assessment Program (EMAP) database	M	X						
Index of Watershed Indicators	M/O	X				X		
Required new Pfiesteria-related efforts								
Data bases symptomology of *Pfiesteria*-related sicknesses	M			X	X			
National Databases: Environmental factors; species distribution; Plankton observer network	M	X	X					X
Databases to include hydrology, nutrient loading, and TMDL's	M						X	
Fish health data bases	M					X	X	

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