APPENDIX F

Brown Tide
Interim Workplan

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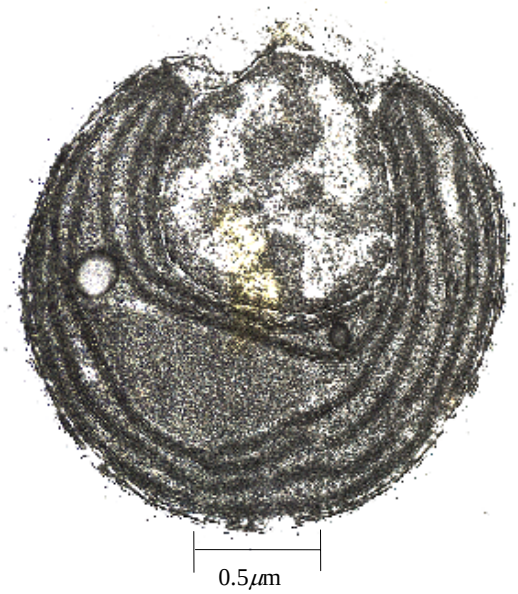
BROWN TIDE WORKPLAN



Transmission electron micrograph of the Brown Tide organism. (x47,000)

AUREOCOCCUS ANOPHAGEFFERENS

("golden sphere") *("causing cessation of feeding")*

An Overview of Ongoing and Historical Research and an Identification of Future Research Priorities

Brown Tide Steering Committee

Coordinated by: Suffolk County, N.Y.
Robert J. Gaffney, County Executive

Interim Workplan — Rev. May, 1998

This interim document has been prepared by the Brown Tide Steering Committee, an ad hoc advisory committee coordinated by the Office of the Suffolk County Executive. For additional information, or to provide comments, please contact: Suffolk County Dept. of Health Services, Office of Ecology, Riverhead County Center, Riverhead, N.Y. 11901, (631) 852-2077.

NOTE: Appendices referenced in this Brown Tide Workplan are available upon request from the PEP Program Office.

FOREWORD

This revised Workplan has been prepared to include newly funded research projects, and is being issued in anticipation of the spring, 1998 Brown Tide Research Initiative Symposium. A more substantial revision of this Workplan, incorporating results of ongoing research initiatives, will be produced subsequent to that Symposium.

The publication history of this Workplan is as follows:

Revised Draft Workplan, May 19, 1997 — The first complete draft Workplan which incorporated comments from the full Brown Tide Steering Committee. Followed the 1997 Brown Tide Research Initiative Symposium.

Interim Workplan, June 3, 1997 — The first official Brown Tide Steering Committee product, which incorporated comments on the May 19, 1997 Revised Draft.

Interim Workplan, Rev. June 17, 1997 — A revised workplan, based on Committee recommendations to include the following priority: mesocosm and laboratory experiments to determine the Brown Tide growth response to additions of selected nutrients and trace elements.

Interim Workplan, Rev. February 23, 1998 — A revised workplan, based on funding of three new projects:

- *Dissolved Organic Nitrogen and Brown Tide Blooms in Long Island's Coastal Waters: Testing the Groundwater Hypothesis* (J. LaRoch *et al*.)
- *Differential Phytoplankton and Microzooplankton Analyses in Long Island Bays* (D. Lonsdale *et al*.)
- *Genetic Variability among Spatially and Temporally Isolated Blooms of the Brown Tide Microalga*, A. Anophagefferens (Stabile *et al*.)

Interim Workplan, Rev. May, 1998 — A revised workplan, based on research results reported in the 1998 Brown Tide Research Initiative Symposium.

BROWN TIDE WORKPLAN

1. SUMMARY

Significant progress has been made with respect to understanding brown tide onset, persistence, cessation, and impacts on shellfish, as well as related biological, physical, and chemical factors. However, substantial additional research is needed. This Workplan estimates that, over the next three years, a total of at least $2.1 to $2.8 million would be necessary to conduct high priority research efforts (see sections A and B below). This initial estimate is probably conservatively low, and is provided for purposes of preparing an interim Workplan based on readily available information.

A) Brown Tide Research Initiative (BTRI)

As a result of the Brown Tide Research Initiative (BTRI) process, three areas of research have been identified as specifically warranting additional funding. Cumulatively, these areas of research would require approximately $400,000 to $600,000. One specific project proposal which has been deemed worthwhile, but which is not being conducted due to funding restrictions, is:

1) Investigations of groundwater, and its various constituents, with respect to Brown Tide blooms.

Additionally, BTRI Committee members recommended development of a Request for Proposals for the following specific research needs:

1) Modelling of nutrient budgets.
2) Investigation of viral/pathogen activity as it may affect Brown Tide.

B) Brown Tide Summit

In addition to the above projects, substantial research should be performed on physical, chemical, and biological factors related to Brown Tide, as well ecological effects of the organism. These additional research priorities are based on a review of *Brown Tide Summit* (Oct. 1995) recommendations in light of historical and ongoing research. *Summit* recommendations are included as Workplan research project priorities only where the *Summit* recommendations address substantively critical topics, where data is needed in the immediate future, and where there is still a research gap (*i.e.*, incomplete research, or no ongoing research). The range of funding needed to adequately address these projects is estimated to be approximately $1.4 to $1.8 million to conduct projects in the following areas:

1) Role of allelopathy in securing for the Brown Tide a competitive edge over other microalgae.
2) Autolysis as a factor related to Brown Tide cessation.
3) Possible relationships between benthic-pelagic coupling and the Brown Tide, including:
   a) Benthic filter-feeders and the removal of suspended particles, and
   b) Resuspension of bottom material and “conditioning” of the water column.
4) The relationship between historical data on meteorological and oceanographic parameters and the occurrence and distribution of Brown Tide in the Peconic Bays system and other systems on the East Coast.

5) Quantitatively describing the temporal and spatial (3-dimensional distribution) of biological, chemical, and physical parameters associated with Brown Tide. A Brown Tide bloom detection and monitoring system based on remote sensing should be developed.

6) Continuous monitoring of various chemical and physical parameters in the field before, during and after Brown Tide blooms.

7) Mesocosm and laboratory experiments to determine the Brown Tide growth response to additions of selected nutrients and trace elements. One possible hypothesis that the mesocosm experiments could test is that the Brown Tide has a competitive advantage in conditions of low dissolved inorganic nitrogen DIN supply, and that limited, transient additions of DIN could mitigate Brown Tide blooms.

8) Effects of Brown Tide on commercially important bivalves and other filter feeders, and optimization of shellfish management programs in the presence of Brown Tide.

9) Effects of Brown Tide on other ecosystem elements, such as eelgrass, and optimization of relevant management programs in the presence of Brown Tide.

C) Next Steps

The Workplan is an "interim document", to be refined and updated periodically. The Brown Tide Research and Management Steering Committee *("Steering Committee")* should further analyze research needs, and should consider issuing a Request for Pre-Proposals based on anticipated funding sources.

2. INTRODUCTION

After the Brown Tide bloom in the summer of 1995 (see Brown Tide fact sheet in **Appendix A**), the Brown Tide Summit of October, 1995 again galvanized support behind a comprehensive program of Brown Tide research. Some Summit participants expressed frustration that historic research was intermittent, uncoordinated, and underfunded. At the Summit, significant progress was made in expanding upon historical knowledge of research needs. Recommendations on additional research dealing with physical, chemical, and biological factors related to Brown Tide were made by Summit work groups.

Also at the Summit, critical commitments for Brown Tide research funding were made. The NOAA Coastal Ocean Program announced that $1.5 million, over three years, would be used for Brown Tide funding. Also, Brookhaven National Lab (BNL) and the Suffolk County Executive announced the Brown Tide Monitoring Network (discussed below), which uses $100,000 in Suffolk County funding with at least that much match from BNL.

As a result of the Summit, the Brown Tide Research Initiative ("BTRI") Committee was formed to prepare a Request for Proposals (RFP), review research proposals, and assist in managing the NOAA Coastal Ocean Program funding. That Committee includes NOAA, N.Y. Sea Grant, NYS Dept. of Environmental Conservation, the Suffolk County Executive, the U.S. Environmental Protection Agency (EPA)/Peconic Estuary Program (PEP), a local government representative, a citizen representative, and a South Shore Estuary Reserve (SSER) representative.

Another Committee, the Brown Tide Steering Committee, was also proposed by various Federal, State, and local representatives to more broadly coordinate and guide Brown Tide research and management efforts. The Steering Committee's goals are to:

1) Coordinate research efforts funded and performed by various entities.
2) Assist in dissemination of information.
3) Develop and continually refine and update research work plans, by systematically organizing and summarizing results of previous and ongoing Brown Tide research efforts, and identifying priorities for additional research needs.
4) Estimate funding needs to conduct necessary additional research.

This "Workplan" deals primarily with goals 3 and 4, but also serves to coordinate and disseminate information about ongoing efforts. The Steering Committee, however, should pursue several other mechanisms to further its goals, including routine distribution of progress reports from ongoing research efforts.

As proposed, the Steering Committee (see **Appendix C** for proposed goals and structure) is comprised of BTRI members, as well as several additional members, including elected officials and representatives from various agencies, citizens groups, and estuary programs, such as Barnegat and Narragansett Bays (see **Appendix D** for mailing list). The Steering Committee is coordinated by Suffolk County. Consensus-building is the process proposed for the Steering Committee, which serves in an advisory role to estuarine research and management programs, elected officials, citizens, and agencies funding and overseeing specific research projects.

3. PROCESS OF IDENTIFYING RESEARCH NEEDS

Research needs are identified in two main ways in this Workplan. The first method is by solicitation of ideas from the research community via Requests for Proposals; this results in specific ideas and very detailed cost estimates. This means is usually employed when there are specific amounts of money available to expend on research, and was used by the BTRI in administering NOAA Coastal Ocean Program funding (see Section 4).

The second mechanism is a systematic organization and review of historical research to identify gaps, resulting in recommendations on generalized research efforts and approximate cost estimates. A major charge of the Steering Committee is to review important research issues in the context of historical and ongoing research, and identify remaining research gaps. The Committee will seek input from technical experts as part of the Workplan process.

4. BTRI APPROACH AND RFPs

The Request for Proposals issued by the BTRI in 1996 resulted in numerous proposals. Although NOAA funding was substantial, it was not enough for all worthwhile proposals.
One specific proposal which was ranked highly, but which could not be funded, included:

1) Investigations of groundwater, and its various constituents, with respect to Brown Tide blooms.

Additionally, BTRI Committee members recommended development of a Request for Proposals for the following specific research needs:

1) Modelling of nutrient budgets.
2) Investigation of viral/pathogen activity as it may affect Brown Tide.

The "nutrient budget" comment has also been highlighted as an important issue by the Steering Committee, particularly in light of a recent hypothesis that Brown Tide may thrive in an environment in which the supply of dissolved organic nitrogen is elevated in relation to a low supply of dissolved inorganic nitrogen (Brookhaven National Lab, LaRoche *et al*). The "nutrient budget" project should further test this hypothesis, and evaluate whether human impacts on the ecology of the Peconic Bay may have contributed to causation of Brown Tide. Ultimately, the hope is that human management (*e.g*., controlling nitrogen inputs) may mitigate conditions which favor Brown Tide blooms.

While the recently funded "Dissolved Organic Nitrogen..." project (see **Appendix B**, project S-19) will be an important step in researching the role of DON in brown tide blooms, it will not completely resolve the nutrient budget issue. For example, additional information on sources of various nitrogen constituents (*e.g*., groundwater and sediment flux) is still necessary.

Each of the three research topics would probably require approximately $150,000 to $200,000 over a two year period, for a total funding need of about $450,000 to $600,000. The Brown Tide Steering Committee, or member agencies, should consider issuing a Request for Pre-Proposals based on anticipated funding sources. These include $450,000 in Suffolk County Capital funds ($300,000 authorized but not appropriated, plus $150,000 recently appropriated; see projects S-18 and S-19 in **Appendix B**) and New York State funding of Brown Tide research (discussed but not committed).

5. HISTORICAL AND ONGOING RESEARCH — SYSTEMATIC REVIEW APPROACH

The Workplan's summary and analysis of research efforts is not intended to be an exhaustive discussion or rigorous compendium. Rather, it is useful as a tool to illustrate the nature and extent of previous research efforts in the context of identified research needs, so that future research needs can be more appropriately identified and justified.

A) Previous and Ongoing Research

A list of previous and ongoing research efforts is included in **Appendix B**. For illustrative purposes, all research efforts are assigned an index number based on primary funding source. These index numbers are used in **Table 1**, which groups project types by categories such as organism onset/growth, decline/cessation, and effects on shellfish. The table also differentiates between lab and field studies, and indicates projects performed retrospectively on existing data.

Several other research and management projects may be *related* to the Brown Tide, and are not included on the research table at this time. For example, bay scallop restorations and eelgrass restocking trials have occurred as part of the PEP. The PEP has also conducted investigations regarding surface water quality monitoring, land use, surface water modelling and sediment nutrient flux. These may be quite important in understanding, and possibly managing, the Brown Tide.

However, for purposes of this Workplan, readily available research lists were utilized; these lists deal with scientific "research" which directly and primarily deals with the Brown Tide.

Table 1 essentially encapsulates information available at the time of the Brown Tide Summit, with the addition of the BTRI projects and the Brown Tide Monitoring Network project. At the Summit, workgroups developed detailed recommendations on research needs in the areas of chemical, physical, and biological factors affecting Brown Tide, as well as Brown Tide ecological impacts. Because these topics include extremely detailed recommendations from work groups, they are used in this Workplan's analysis.

B) Development of Priority Research Recommendations

Tables 2 through 5 list the research areas identified as priorities in the Summit. The tables also note where additional research is necessary on a high priority basis. Research needs are highlighted where Brown Tide Summit recommendations were not acted upon (*i.e.*, no high quality proposals submitted, or no funding available), or where research is ongoing, but substantial additional research is believed to be needed.

In considering the importance of research gaps, areas are designated as "high priority" when the need for the project is both substantively and temporally (*i.e.*, necessary immediately) important. For example, comprehensive Brown Tide modelling is believed to be substantively important, but to a large degree cannot effectively occur on a meaningful level until more is understood about basic Brown Tide physiology. Therefore, it is not a high priority for immediate funding. However, information on differential phytoplankton populations, which would be critical to any eventual model, is a high priority, as it would assist in understanding Brown Tide population dynamics and relationships to other organisms.

The timeframe contemplated by this Workplan is roughly in the range of three years, which is how long it would probably take to complete the round of projects identified as priorities. The nature of the scientific research projects makes it nearly impossible to accurately forecast research priorities beyond that time period. Researchers and managers hope that the Brown Tide mystery will be solved, and that management options may be possible to prevent or minimize impacts of future blooms. Conversely, based on prior experience, it is reasonable to assume that, at the end of three years, scientists may have raised substantial additional questions, which would require substantial additional funding. This Workplan contemplates only the short-term, priority research needs. Of course, the research priority-setting process is fluid, and will change periodically based on new findings.

The "systematic" approach is admittedly less than perfectly rigorous. Research priorities and funding estimates are, to some degree, based on subjective evaluations and subject to some degree of error. This is, hopefully, minimized by identifying only projects which are clearly high priorities, and specifying a range of likely project costs which are conservatively low. In this manner, the Workplan specifies a "minimum" of research needs.

Also, research is, by its very nature, somewhat speculative. No one can be sure how useful the results of any one project, or even a set of projects, might actually be in helping to understand or manage the Brown Tide. The fluid nature of the Workplan, which will be periodically updated, should address the need to continually review the results of current research and identify remaining research needs.

Potential problems in the prioritization approach will also be minimized by review of, and input to, the Workplan by a broad range of persons with expertise and interest in the topic. In the final analysis, the Brown Tide Steering Committee, and its Workplan, are advisory in nature, and final funding decisions on specific projects are left to the entities which actually fund research work. The Workplan is intended to guide funding entities, proposers, and policymakers involved in funding decisions. The Steering Committee believes that the Workplan approach is the best way to accomplish these ends.

6. PRIORITY RESEARCH RECOMMENDATIONS

The systematic review of Brown Tide Summit recommendations has resulted in several recommended projects, which would require approximately $1.8 to $2.4 million to perform. Cost estimates for the projects are provided as a range of probable costs of $150,000 to $200,000 per project, assuming two years for each project. The estimates are based on professional judgement and prior experience with comparable projects. It is possible that given projects could be performed for less than the assumed cost range; conversely, some projects could cost substantially more, particularly if significant laboratory analysis and/or field effort is required. For purposes of estimating the approximate range of research funding necessary, the estimates are believed to be reasonable.

It is important to emphasize that the overall cost estimates in this interim Workplan are probably too low, as they were prepared based on readily available information, using cost estimates which are conservatively low and defensible. While a few projects could cost less that $150,000 to $200,000, it is likely that several could cost substantially more, particularly the ones which would be labor-intensive and multiple-year efforts. The estimates are provided for purposes of preparing an interim Workplan, and the Steering Committee should consider expanding upon, or refining, the estimates, as deemed appropriate.

These priority research recommendations are summarized as follows.

A) Biological

Many of the key areas of research recommended by the Brown Tide Summit workgroup are being conducted as part of the BTRI. These include efforts to isolate of multiple and axenic cultures, investigation of iron as a possible trigger for the Brown Tide bloom by development of a metabolic marker, a study of Brown Tide energy and nutrient acquisition in low light, and additional investigations into zooplankton and phytoplankton interactions. However, several other important areas were not addressed. These are discussed below.

1) Role of Allelopathy in Securing for the Brown Tide a Competitive Edge over Other Microalgae

Allelopathy has been suggested as a possible mechanism for Brown Tide blooms, whereby the Brown Tide can interfere with the growth or survival of other organisms through production of toxins or other substances. This is a significant gap in Brown Tide research.

2) Factors Related to Brown Tide Cessation, including Autolysis

Prior research suggests that viruses may be involved in the cessation of Brown Tide blooms. The BTRI identified viruses as an additional research area, recognizing the importance of verifying and characterizing the nature and extent of viruses in ending Brown Tide blooms. Another

research area identified in the Brown Tide Summit is the determination of whether the Brown Tide organism breaks down and lyses itself, as is the case in some marine microalgae.

3) Possible Relationships between Benthic-Pelagic Coupling and the Brown Tide, including: Benthic Filter Feeders and the Removal of Suspended Particles, and Resuspension of Bottom Material and "Conditioning" of the Water Column

Additional research is needed to characterize how benthic filter-feeders impact water column suspended particle loads and the size structure of phytoplankton communities, as well as how human-related shellfishing practices may have affected ecological processes by removal of shellfish or resuspension of sediments.

B) Physical

The most sweeping recommendation, regarding a quantitative model, is probably unrealistic, due to the absence of basic data to construct the model, together with the prohibitively high cost of constructing the model. However, three areas are appropriate priorities for immediate research, as follows.

1) *What Relationship Exists between Historical Data on Meteorological and Oceanographic Parameters and the Occurrence and Distribution of Brown Tide in the Peconic Bays System?*

A comprehensive and systematic review and reporting on all available data has not been performed. Physical scientists/physical oceanographers or others familiar with advanced statistical techniques should evaluate a number of East Coast embayments. Climatic data, such as rainfall and wind direction, should be gathered and analyzed at a fairly high-resolution level, perhaps weekly. Satellite data, and any other available multi-frequency data, should be systematically used. Advanced statistical methods, such as "intervention analysis," should be considered. Specific possibilities which should be considered include geographic orientation of bays (in combination with local wind vectors and poor flushing) and warm core ring water drifting onto the East Coast to "seed" the area with an offshore bloom.

2) *How Can We Best Quantitatively Describe the Temporal and Spatial (3-Dimensional Distribution) of Biological, Chemical, and Physical Parameters Associated with Brown Tide?*

While a comprehensive three-dimensional model is not a realistic short-term goal, data should be collected which could eventually support model development, and which would have independent utility, as well. The following topic deals with such data collection: the development of an effective remote sensing system for Brown Tide blooms to better track the spatial and temporal variability of blooms.

C) Chemical

As with the "biological" recommendations, many of the key areas of research recommended by the Brown Tide Summit workgroup are being conducted as part of the BTRI. These include a study of the effect of metals and organic nutrients with respect to Brown Tide. Several other projects deal jointly with interrelated chemical and biological issues (*e.g*., iron study discussed above; review of chemical and biological data in Narragansett Bay). The following areas, however, warrant additional investigation.

1) Continuously Monitor Various Chemical and Physical Parameters in the Field before, during and after Brown Tide Blooms.

Although the Brookhaven National Lab Brown Tide Monitoring Network project will initiate some continuous monitoring in 1997, the project will terminate within a year. Additional support will be needed to maintain and, possibly, expand the program. This project would probably require approximately $50,00–100,000.

As with differential phytoplankton data, an "early warning/emergency response" plan may be appropriate (reduce number of stations, and increase when Brown Tide begins blooming). Also, efforts could be concentrated in "bloom initiation" periods (May). However, cost savings in reducing number of continuous stations and/or time periods should be carefully weighed against the value of "out-of-Brown Tide season" data.

2) Perform Mesocosm and Laboratory Experiments to Determine the Brown Tide Growth Response to Additions of Selected Nutrients and Trace Elements.

To test the theory that Brown Tide bloom onset conditions are optimized when supply is elevated in relation to a low DIN supply (discussed above), and to evaluate possible mitigation strategies, field and laboratory experiments should be performed to determine the effects of various nitrogen constituents on Brown Tide. Other nutrients and trace elements could be included as well. A factorial-grid of DON/DIN ratio, timing of DON/DIN manipulation, and competitor phytoplankton species could be useful for a critical evaluation of the hypothesis. Such an approach could be best accomplished with closely coordinated lab and mesocosm experiments. One possible hypothesis that the mesocosm experiments could test is that the Brown Tide has a competitive advantage in conditions of low dissolved inorganic nitrogen DIN supply, and that limited, transient additions of DIN could mitigate Brown Tide blooms.

D) Ecological Effects

While ecological effects are certainly important, the consensus at the Summit seemed to be that the most critical threshold issues relate to the dynamics of the Brown Tide organism itself. Thus, priority research recommendations relate to the Brown Tide, rather than its impacts. The Steering Committee

will revisit this issue to evaluate whether additional priorities should be placed in the area of ecological effects.

With regard to shellfish, since there is a real possibility that the Brown Tide may never be "controllable," scientists and resource managers should also focus on the practical aspects of ecological effects, with special emphasis on the portions of the ecosystem tied to public use. These efforts would involve characterizing Brown Tide impacts on resource species (how much Brown Tide is tolerated, and for how long). Ultimately, the goal would be to characterize the sustainability of various species, and provide guidance on likelihood of resource availability. There are numerous specific and practical management implications of this "research," including identification of species that have the best prospects for long-term sustainability, and in what areas; recommendations on where to site, and how to manage, hatchery facilities; where to transplant scallops to maximize likelihood of survival and population; and ways to manage shellfish in the event of a bloom, such as moving scallops to areas less likely to be impacted.

Also, information on why Brown Tide affects filter feeders may be important to understand why it is so successful.

Specific research area recommendations for shellfish include:

- Identify mechanism by which Brown Tide affect actual (whole) scallops (*e.g.*, chemical mediator affecting feeding mechanism).
- Evaluate threshold density and duration of Brown Tide exposure that impacts scallops.
  - Characterize scallop recovery time after short exposure.
  - Identify "point of no return" after which time scallops will not recover.
- Study impacts on other species (*e.g.*, clams, oysters).

Living resources other than scallops, clams, and oysters which may be of concern with respect to the Brown Tide include submerged aquatic vegetation (particularly eelgrass), finfish, and crustaceans. The negative impacts on eelgrass are suspected but not confirmed; there were massive die-offs of the grasses reported during the first bloom in l985, but apparently not in subsequent blooms. Eelgrass is a critical habitat for scallops and other organisms. Knowledge of Brown Tide impacts on eelgrass, and eelgrass recovery dynamics, may be important in providing guidance on likelihood of resource availability and in directing management programs, such as eelgrass and scallop transplant efforts.

The impacts of the Brown Tide on finfish and crustaceans are completely unknown. There is some anecdotal information that these organisms moved out of the estuary in response to the bloom but these have not been confirmed. The latter impacts may be important with respect to the role of the estuary, particularly the waters in the western end, as a nursery and feeding ground for coastal finfish species as well as crustaceans. Although not of first priority, some consideration should be given in the future to examining the effects of the bloom on crustaceans and species of finfish which use the estuary for spawning and juvenile feeding.

For purposes of this workplan, the "ecological effects" research topics are grouped into the following two areas (based on **Table 5**), although it is highly likely that more than two projects would be necessary to accomplish the above-discussed objectives.

1) How does Brown Tide impact commercially important bivalves and other filter feeders, and how can shellfish management programs be optimized in the presence of Brown Tide?
2) What is the effect of Brown Tide on other ecosystem elements, such as eelgrass, and how can relevant management programs be optimized in the presence of Brown Tide?

Table 1. Concluded and Ongoing Brown Tide Research.

I. LAB STUDIES

A) What factors control the growth of brown tide?

1. Organism Physiology
    a. Role of macro & micronutrients
        Cosper (S3,S4), LaRoche & Falkowski (BNL), Glibert & Kana (B4), Keller & Sieracki (B5), Carpenter (N1), LaRoche *et al*. (S-19)
    b. Role of Light (Photosynthetic Physiology)
        Glibert & Kana (b4), Keller & Sieracki (B5)
    c. Role of trace metals & chelators
        Cosper (B3), Boyer (S16), Boyer & LaRoche (B2)
    d. Growth rate measurements
        Carpenter (N8)
2. Competitive Interactions
    a. Allelopathy (no known research performed to date)
    b. Interspecific competition
        Keller & Sieracki (B5)
    c. Axenic Cultures and Bacterial Associations
        Levandowsky (S11), Wikfors & Robohm (B7), Andersen (B1), Mahoney (S14)
3. Genetics of *Aureococcus*
        Andersen (B1), Stabile *et al*. (E-1)

B) What factors control bloom progress, decline and cessation?

1. Effect of grazers on brown tide
        Lonsdale (S13), Keller & Sieracki (B5), Cosper & Lonsdale (N2)
2. Effect of viruses on brown tide
        Cosper (N3)

C) How does bloom affect the ecosystem?

1. Effect of brown tide on shellfish
        Bricelj (S1, N6)

II. FIELD STUDIES

A) What factors control growth of brown tide?

1. Organism physiology & bloom dynamics
    a. Role of macro & micronutrients
        BTCAMP, PEP, Cosper (N4), Sañudo–Wilhelmy *et al*. (B8), LaRoche *et al*. (S-19)
    b. Role of Light (Photosynthetic Physiology)
        Wirick & Falkowski (S17-BNL)
    c. Role of trace metals and chelators
    d. Productivity studies
        Cosper (S8), Sañudo-Wilhelmy *et al*. (B8)

Table 1. Concluded and Ongoing Brown Tide Research. (continued)

II. FIELD STUDIES (continued)

e. Bloom dynamics
BTCAMP, PEP, Anderson (S9), Levandowsky (S11)
f. Genetic Variability, Stabile *et al*. (G-1)

2. Competitive interactions
a. Microzooplankton-mesozooplankton coupling
Caron & Lonsdale (B3), Lonsdale *et al*. (S-18)

3. Physical Factors
Siddall (S7), BTCAMP, PEP, Beltrami (S12), Wilson & Beltrami (S15-N7)

B) Effects of brown tide on ecosystems

1. Effects of brown tide on eelgrass
Dennison (S2,S5)
2. Effects on scallop landings
Siddall (S6)
3. Effects on microbial food webs
Lonsdale & Taylor (N5)

III. RETROSPECTIVE ANALYSIS

1. Long Island Brown Tide
LaRoche & Falkowski (BNL)
2. Rhode Island Brown Tide
Smayda (B6)

* "N" = NY Sea Grant-funded; "S" = Suffolk County-funded; "B"= BTRI/NOAA COP funded (See **Appendix B**).

Table 2. Brown Tide Summit and Workplan Research Recommendations Biological Factors.

Brown Tide Summit — Recommended Research Category	Brown Tide Workplan — Priority Research Area
1.1 What factors control the growth of brown tide?	
1.1.A. Nutritional requirements of brown tide	
1. *Role of macro-, micro-, and trace organic nutrients in* A. Anophagefferens *growth.*	
2. *Role of variation in light (including shade adaptation and photoperiod) in affecting the nutritional requirements or preferences of* A. anophagefferens.	
3. *Role of various metals and chelating compounds in altering the nutritional requirements/preferences of* A. anophagefferens.	
4. *Role of heterotrophy as a means of supplemental nutrition of* A. anophagefferens.	
1.1.B. Competitive interactions involving the brown tide organism	
1. *Role of allelopathy in securing for the brown tide a competitive edge over other microalgae.*	**X**
2. *Role of bacterial associates in mediating the brown tide organism's response to environmental conditions and particularly in affecting its nutrition.*	
1.2. What factors control the removal of brown tide and how do they relate to bloom dynamics?	
1.2.A. Timing of grazer presence and grazing activity.	
1. *Extensive examination of potential grazers.*	
2. *The palatability/susceptibility of the of the brown tide organism to grazers.*	
1.2.B. Activity of viruses	
1.2.C. Autolysis	**X**
1.3 What aspects of benthic-pelagic coupling may be important in brown tide blooms?	
1.3.A. Benthic filter-feeders and the removal of suspended particles.	**X**
1.3.B. Resuspension of bottom material and "conditioning" of the water column.	**X**
1.4 Basic Organism Physiology — Misc.	
1.4.A. Axenic Culture	

Table 3. Brown Tide Summit and Workplan Research Recommendations Physical Factors.

Brown Tide Summit — Recommended Research Category	Brown Tide Workplan — Priority Research Area
2.1 What relationship exists between historical data on meteorological and oceanographic parameters and the occurrence and distribution of brown tide in the Peconic Bays System? Other systems?	**X**
2.2 Can a simple quantitative model be developed that explains historic and current trends in the variation of these parameters throughout the system?	
2.3 How can we best quantitatively describe the temporal and spatial (3-dimensional distribution) of biological, chemical, and physical parameters associated with brown tide?	**X***

* Differential phytoplankton analysis and remote sensing of brown tide.

Table 4. Brown Tide Summit and Workplan Research Recommendations Chemical Factors

Brown Tide Summit — Recommended Research Category	Brown Tide Workplan — Priority Research Area
3.1 What is the role of major nutrients (*e.g.*, N, P), including organic nutrients, in stimulating a brown tide bloom?	
3.2 What is the role of micronutrients in stimulating brown tide blooms?	
3.3 Research objectives for macro- and micronutrients (Culture based and field experiments)?	
3.3.A. Calculate budgets for the major nutrients (N, P, Si) to the extent possible using existing data.	
3.3.B. Continuously monitor various chemical and physical parameters in the field before, during, and after brown tide blooms.	**X**
3.3.C. In an effort to determine the relative importance of macro- and micronutrients in stimulating the growth of A. anophagefferens, a suite of experiments should be conducted in the field, with mesocosms and with bottle experiments. The goal of these experiments is to determine the growth response to additions of selected nutrients and trace elements. A parallel set of measurements should be conducted in the laboratory using axenic cultures.	**X**
3.3.D. As the efforts proceed to identify chemical factors important in stimulating brown tide blooms, it is necessary to characterize important sources and sinks of such factors. Sources include, but are not limited to, the flux from bottom sediments, groundwater inflow, sewage treatment plan effluent, atmospheric deposition, and stormwater runoff.	

Table 5. Brown Tide Summit and Workplan Research Recommendations Ecological Effects.

Brown Tide Summit — Recommended Research Category	Brown Tide Workplan — Priority Research Area
4.1 How does brown tide impact commercially important bivalves and other filter-feeders?	**X**
4.1.A. Brown tide's effect on bivalve physiology	
1. What is the in vivo mechanism responsible for grazing suppression and other adverse effects?	
2. What are the density- and time-dependent effects of brown tide on survival, growth, and reproduction of bivalves?	
3. How does brown tide cause recruitment failure and other reproductive impacts in bivalve mollusks?	
4.1.B. Development of a brown tide bioassay	
4.2 How can shellfish management programs be optimized in the presence of brown tide?	**X**
4.2.A. Determination of management approaches: How can management practices be improved to reduce losses from brown tide?	
4.2.B. What is the effect of brown tide on other ecosystem elements?	
4.3 What is the effect of brown tide on other ecosystem elements?	**X**
4.3.A. Impacts on submerged aquatic vegetation (SAV)	
4.3.B. Impacts on secondary consumers	
1. Does brown tide-related light attenuation and increased turbidity affect organisms, such as finfish, that rely on visual cues in feeding and predator avoidance?	
2. What are the effects of brown tide-related eelgrass losses on secondary consumers?	
4.4 Are there multiple strains of brown tide of varying relative toxicity?	

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