Aquatic Ecosystem Health and Management Society

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A Brown Tide Bloom Index based on the potential harmful effects of the brown tide alga, *Aureococcus anophagefferens*

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Harmful algal blooms are an increasing phenomenon in coastal areas of the world. Recurring harmful brown tides caused by the minute alga, Aureococcus anophagefferens*, are a regional problem in the northeast Atlantic states of the United States. Brown tide blooms may cause significant ecological impacts on natural resources. A Brown Tide Bloom Index was developed based on published scientific studies and agency reports that relates concentrations of the brown tide organism to potential negative impacts on natural resources including shellfish, seagrasses and protozoa. For the first time, the index provides terminology that can be used to convey accurate information about impacts to natural resources resulting from concentrations of brown tide to scientists, environmental managers and the public. The purpose of the Brown Tide Bloom Index is to provide a metric, based on available scientific studies, which can be used by environmental managers to communicate the magnitude of brown tide blooms and impacts to natural resources. The Brown Tide Bloom Index includes three categories of brown tide blooms: Category 1 blooms (algal concentrations at <35,000 cells ml^{-1}) have no reported impacts; Category 2 blooms (≥35,000 to <200,000 cells ml^{-1}) have potential negative impacts on feeding and growth in shellfish; Category 3 blooms (≥200,000 cells ml^{-1}), discolor the water a yellow-brown and may cause severe impacts and mortality on shellfish, reduction in seagrasses and planktonic organisms.*

Keywords: harmful algal blooms, metric

Introduction

Harmful algal blooms are an increasing phenomenon in coastal areas of the world. Harmful brown tides caused by the minute (ca. 2–3 μm in diameter) pelagophycean algae, *Aureococcus anophagefferens*, are a chronic problem in the coastal bays in the northeast Atlantic region of the United States. Brown tide blooms, first observed in Narragansett Bay, RI and the non-contiguous coastal bays of Long Island, NY in 1985, caused massive damage to shellfish (Cosper et al., 1987; Sieburth et al., 1988; Nuzzi and Waters, 1989). While these blooms did not recur in Narragansett Bay (Smayda and Borkman, 2000), they have chronically appeared in coastal bays of Long Island, NY. Since then brown tide has also been identified in Barnegat Bay, NJ (NJDEP, 1989, 1995, 1999; Cosper et al., 1990; Nuzzi et al., 1996; Gastrich, 2000a, b, 2001; Gastrich et al., 2000, 2001), the coastal bays of Delaware (Humphries, 2001) and Maryland (Wazniak, 2001). The current southern extent of brown tide *Aureococcus anophagefferens* blooms in the U.S. is Chincoteague Bay, MD (Wazniak, 2001). Additionally, brown tides have been documented outside the

Aquatic Ecosystem Health & Management, 5(4):435–441, 2002 © 2002 AEHMS 1463-4988/02 $12.00 + .00
DOI: 10.1080/14634980290002011

U.S. in South Africa during the 1990s (Probyn et al., 2001).

Brown tide blooms continue to be a recurring problem in the Northeast region and have been extensively monitored and studied in coastal Long Island bays, including Peconic Bay, Great South Bay, Moriches Bay and Shinnecock Bay, since the mid-1980s (Nuzzi, 2001). The states of New Jersey, Maryland and Delaware have only recently instituted monitoring programs and/or special studies to characterize the spatial and temporal extent of the brown tide blooms in their coastal embayments (Gastrich, 2001; Humphries, 2001; Wazniak, 2001). While these blooms are not reported to be harmful to bathers or consumers of shellfish, they can cause significant ecological impacts to shellfish and eelgrasses (Bricelj and Lonsdale, 1997).

Because of the regional nature of brown tide blooms, government agencies and scientists need to communicate with each other and the public regarding the status of blooms in the region as well as potential impacts. Previously, information about brown tide blooms has been qualitatively reported as "significant," "major," "moderate," "small" and "low" blooms by various groups and individuals based upon different concentrations and/or different understandings of the impacts to natural resources. Hence, there is a need to have a consistent terminology used by agencies and scientists in reporting these blooms that is based on specific concentrations and impacts to natural resources.

Since the term Harmful Algal Blooms refers to algal blooms that either contain a toxin or have negative ecological impacts, a bloom index may be related to one or both of these impacts. When the toxin is known and well understood, a toxicological index can be defined based on the concentration of the toxin in the water or in fish tissue (Suter, 1993). For example, Cosper and Cerami (1996) developed a system for harmful algal blooms that used 15 categories and criteria that were mainly directed at human health concerns and not readily adaptable to brown tide blooms. Although the toxins associated with brown tide have not yet been defined, brown tide blooms can kill marine organisms. Therefore, an index based upon the ecological impacts is needed. Many times a bloom may be defined by the concentration at which the water turns a specific color versus the actual ecological impacts. Our objective is to describe a Brown Tide Bloom Index (BTBI) which will communicate information about the magnitude of brown tide blooms and their potential impacts on natural resources in a way that can be readily understood by scientists and environmental managers (Gastrich et al., 2001).

Methodology

Existing laboratory and field research studies that specifically related concentrations of the brown tide organism, *Aureococcus anophagefferens*, to negative ecological impacts were identified. The available data from studies fit into a three category continuum system which could be used to generally describe the magnitude of brown tide blooms based on concentrations and related ecological impacts.

In developing the BTBI, several assumptions were made: 1) the index addresses only the blooms caused by *Aureococcus anophagefferens* in the northeast states and does not apply to the Texas brown tides caused by *Aureoumbra lagunensis* or other brown alga (e.g., Suldanha Bay, S.A.); 2) appropriate methods were used to collect water samples and enumerate *Aureococcus anophagefferens* (e.g., Anderson et al., 1989, 1993; Caron, 2001; D.A. Caron et al., Univ. S. Calif, unpubl. data); 3) the index is not meant to be a toxicity index (e.g., it is not based upon an identified toxin and a concentration-response) although it assumes some level of toxicity to the organism; 4) the index does not predict impacts of specific concentrations of *Aureococcus anophagefferens* concentrations in natural populations but it does provide information on potential impacts and it is assumed that the increased concentrations and/or increased duration of blooms may potentially cause more severe impacts (e.g., dense shading of seagrasses); and 5) because the index categories are arbitrarily based on available scientific data and field observations, the use of the index is independent of differing monitoring designs; therefore, the highest observed *Aureococcus* concentrations should be used when applying the index.

Results

Table 1 summarizes potential ecological impacts to natural resources at different concentrations of *Aureococcus anophagefferens* into three general categories based upon scientific studies. Category 1 represents the lowest level of *Aureococcus* concentrations, $<35{,}000$ cells ml^{-1}, a concentration that scientific studies have shown produces no toxic effects on shellfish. As well, no other ecological impacts have been shown at this level. Juvenile *Mercenaria mercenaria* (hard clams) have been reported to maintain normal feeding

Table 1. Brown Tide Bloom Index: *Aureococcus anophagefferens*, cells ml^{-1}. Table is based on available scientific data; some of the available data may need to be reassessed through additional research; and there may be complex ecological interactions (e.g., trophic level interactions, presence of additional algal species, etc.) which may affect impacts which are not fully addressed in the table; Categories are relative and related to different threshold concentrations of brown tide.

Cells ml^{-1}	Index (Category)	Potential Impact	Sources
<35,000	1	• **Shellfish:** no known impact on *Mercenaria mercenaria* juveniles	Bricelj et al., 2001; Schaffner, 1999
35,000 to <200,000	2	• **Shellfish Impacts**	
		• **Hard Clams** (*Mercenaria mercenaria*)	
		The threshold concentration of toxic clones that inhibit clearance (feeding rates) on co-occurring phytoplankton species was determined to be at 35,000 to 50,000 *Aureococcus* cells ml^{-1} for juvenile (10 mm) hard clams.	Bricelj et al., 2001; Bricelj, 1999; Schaffner 1999;
		Short term feeding study (1–2 hrs) showed that an isolate of *Aureococcus* (from West Neck Bay, NY, 1995) at ≥35,000 cells ml^{-1} significantly reduced feeding (clearance rate) of juvenile hard clams (ca. 10 mm); longer term growth studies (2–3 wks) showed similar results.	Schaffner, 1999; Bricelj, 1999
		• **Mussels** (*Mytilus edulis*)	
		At 1–3 × 10^5 *Aureococcus* cells ml^{-1}, mussels in bloom areas show stronger growth reduction than quahogs relative to non-bloom sites and growth of juvenile mussels in Peconic Bay significantly reduced	Bricelj and Borrero, unpubl. Data, reported in Bricelj and Lonsdale, 1997; Bricelj and Lonsdale, 1997
		• **Bay Scallops** (*Argopecten irradians*)	
		Significant growth reduction and high mortalities of bay scallop larvae at 190,000–750,000 *Aureococcus anophagefferens* ml^{-1}	Gallagher et al., 1989
200,000 to >1,000,000	3	• **Physical Characteristics**	
		Water becomes discolored at 200,000 *Aureococcus* ml^{-1}	W. Dawydian and R. Nuzzi, Suffolk County Department of Health Services, (pers. comm)
		• **Shellfish Impacts**	
		Bivalves may experience sub-lethal, adverse effects at *Aureococcus* densities of 10^5 cells ml^{-1}	Bricelj and Lonsdale 1997; Bricelj and Kuenster, 1989
		• **Mussels and Hard Clams**	
		Grazing (clearance) rates of adult *Mytilus edulis* and *Mercenaria mercenaria* markedly inhibited during Narragansett Bay brown tide in 1985 (*Aureococcus* concentrations >10^6 cells ml^{-1}); dilution experiments in Narragansett Bay water showed *Aureococcus anophagefferens at* >2.5 × 10^5 cells ml^{-1} were required to inhibit clearance rates of adult *Mytilus edulis* on *Isochrysis galbana*	Tracey, 1988
		Effects of toxic strains of >10^6 ml^{-1} *Aureococcus* on clearance (feeding) rates of juvenile mussels	Tracey, 1988; Bricelj, 1999; Bricelj et al., 2001
		Growth of juvenile mussels significantly reduced in Peconic Bay sites at *Aureococcus* concentrations ~100,000 to 300,000 cells ml^{-1}	Bricelj and Lonsdale, 1997
		Growth of juvenile *Mercenaria mercenaria* undetectable at toxic *Aureococcus* clone concentrations ≥400,000 cells ml^{-1}	Bricelj et al., 2001

(Continued on next page)

Table 1. Brown Tide Bloom Index: *Aureococcus anophagefferens*, cells ml^{-1}. Table is based on available scientific data; some of the available data may need to be reassessed through additional research; and there may be complex ecological interactions (e.g., trophic level interactions, presence of additional algal species, etc.) which may affect impacts which are not fully addressed in the table; Categories are relative and related to different threshold concentrations of brown tide. *(Continued)*

Cells ml^{-1}	Index (Category)	Potential Impact	Sources
		• **Bay Scallops** (*Argopecten irradians*)	Cosper et al., 1997
		Massive recruitment failures of the 1985 year class of the bay scallop, *Argopecten irradians*, as a result of brown tide blooms in Long Island embayments	
		High mortalities (up to 64–82%) of adult bay scallops in Peconic Bay after the 1995 brown tide bloom (densities reached 0.8–2.2 × 10^6 cells ml^{-1} measured from incidence of articulated "clucker" shells).	C. Smith, pers. comm. in Bricelj and Lonsdale, 1997
		Aureococcus anophagefferens causes significant growth reduction and high mortalities of *Argopecten irradians* larvae at concentrations of 190,000–750,000 cells ml^{-1}.	Gallagher et al., 1989
		Field data suggest inhibitory effects on growth of bay scallops at ca. 2 × 10^5 *Aureococcus* cells ml^{-1} in Long Island Bays	Bricelj et al., 1987
		• **Hard Clams and Mussels**	
		No significant growth (measured by change in the ash-free dry weight or organic weight of juvenile hard clams 6 mm in initial shell length) of juvenile hard clams at concentrations of the same isolate of *Aureococcus* ≥400,000 cells ml^{-1}; similar results with juvenile mussels	Bricelj, 1999
		Observations of a reduction in feeding and development of hard clam larvae, reported by a commercial aquaculture facility, during a 1995 brown tide bloom in Tuckerton Bay, N.J., with Aureococcus cell counts ranging from 1.1 to 1.8 × 10^6 cells ml^{-1}.	Nuzzi et al., 1996
		Reports of reductions in juvenile hard clams during 1999 and 2000 brown tide blooms in Little Egg Harbor (as reported by Biosphere, Inc., an aquaculture facility in Tuckerton, NJ), with *Aureococcus* counts reported >10^6 cells ml^{-1} in 1999, >2.0 × 10^6 cells ml^{-1} in June 2000, and >240,000 cells ml^{-1} in June 2001	Gastrich, 2000a, b; Gastrich, 2001; Gastrich et al., 2000; NJDEP, 1999
		• **Macrobenthos Impacts**	
		Negative impacts to macrobenthos such as eelgrass, *Zostera marina* (e.g., die-off) at *Aureococcus* densities of 0.05 to 2.6 × 10^6 cells ml^{-1} with a mean of 0.66 × 10^6 cells ml^{-1} leading to an increase in light scattering and a severe reduction in light penetration) and bay scallops, *Argopecten irradians* in Long Island Bays (*Aureococcus* concentrations >10^6 cells ml^{-1})	Dennison et al., 1989; Cosper et al., 1987; Bricelj et al., 1987
		• **Planktonic Impacts**	
		From the onset of brown tide in West Neck Bay, N.Y. in 1995 to the peak (*Aureococcus* concentrations of 1.1 × 10^6 cells ml^{-1} microzooplankton population declined from >10,000 to <900 ind. l^{-1}.	Mehran 1996
		Copepod production in Narragansett Bay in 1985 was reduced at *Aureococcus* concentrations of 7.6 × 10^5 cells ml^{-1}.	Durbin and Durbin, 1989
		Copepod production was also reduced in West Neck Bay, NY at *Aureococcus* concentrations of 1.5 × 10^6 cells ml^{-1}.	Lonsdale et al., 1996

activity with normal clearance below this threshold *Aureococcus* concentration (Bricelj, 1999; Schaffner, 1999; Bricelj et al., 2001).

Category 2 blooms are marked by the lower threshold concentration of 35,000 cells ml^{-1} at which concentration scientific studies report a sharp reduction in clearance rates of juvenile *Mercenaria mercenaria* (Schaffner, 1999; Bricelj et al., 2001). At *Aureococcus* concentrations of 50,000 cells ml^{-1}, there was a 94% decline in juvenile *Mercenaria mercenaria* (Bricelj et al., 2001). As Category 2 concentrations increase to less than 200,000 cells ml^{-1}, there are increased ecological effects such as the reduction in the growth of juvenile *Mytilis edulis* (mussels) in Peconic Bay (Bricelj and Lonsdale, 1997) and *Argopecten irradians* (bay scallops) (Gallagher et al., 1989; Tracey, 1988).

Category 3 blooms are demarcated at 200,000 cells ml^{-1} because a yellow-brown discoloration of the water is usually observed (W. Dawydiak and R. Nuzzi, Suffolk County Department of Health Services, pers. comm.) and are open ended at the highest end (highest values currently observed in the field are over 2×10^6 cells ml^{-1}). Several scientific studies document the most severe potential effects occurring in this range to include such significant adverse effects as changes in feeding rates, significant reduction in growth and/or mortalities in adult shellfish, negative impacts to other species (e.g., seagrasses, plankton) and massive recruitment failures at the population level (summarized in Bricelj and Lonsdale, 1997; Tracey, 1988).

Some of the negative impacts related to brown tide concentrations reported from field and laboratory studies using toxic clones of *Aureococcus* show that this range includes inhibited grazing (clearance rates) of juvenile and adult *Mytilus edulis* and *Mercenaria mercenaria* (Bricelj et al., 2001). One study found that the growth of juvenile *Mercenaria mercenaria* was undetectable at clone concentrations $\geq$400,000 cells ml^{-1} (Bricelj et al., 2001). At some of highest reported brown tide bloom concentrations ($0.8–2.2 \times 10^6$ cells ml^{-1}) in the field, there were high mortalities (1995 in Peconic Bay) and massive recruitment failures of the *Argopecten irradians* (1985 Long Island embayments) in New York (Cosper et al., 1987; Bricelj and Lonsdale, 1997), while in Barnegat Bay, NJ, there were observations of reduction in feeding and development of *Mercenaria mercenaria* larvae, reported by a commercial aquaculture facility, during a 1995 brown tide bloom in Tuckerton Bay, N.J., with Aureococcus cell counts ranging from 1.1 to 1.8×10^6 cells ml^{-1} (Nuzzi et al., 1996). Category 3 concentrations were also associated with negative impacts to macrobenthos such as eelgrass, *Zostera marina* (e.g., die-off; Dennison et al., 1989) at *Aureococcus* densities of 0.05 to 2.6×10^6 cells ml^{-1} with a mean of 0.66×10^6 cells ml^{-1} (leading to an increase in light scattering and a severe reduction in light penetration) and *Argopecten irradians* (Cosper et al., 1987; Bricelj and Kuenster, 1989; Bricelj et al., 1987) in Long Island Bays. Lastly, Category 3 concentrations of *Aureococcus* at 1.1×10^6 cells ml^{-1} were associated with microzooplankton population declines in West Neck Bay, NY in 1995 (Mehran, 1996; Lonsdale et al., 1996) while *Aureococcus* concentrations at 7.6×10^5 cells ml^{-1} were associated with reduced copepod production in Narragansett Bay in 1985 (Durbin and Durbin, 1989).

Discussion

The BTBI is intended to be used by scientists and environmental managers to communicate bloom conditions and to inform the public. Some caution is advised when using the index because it is based on available scientific data which may be reassessed through additional research. For example, while no negative impacts have been observed for Category 1 blooms, it should not be assumed that there are no negative impacts because future studies may show adverse effects to specific populations at these levels. Additionally, the index does not incorporate complex ecological interactions that have additional impacts on natural resources.

In using the index, any concentration of *Aureococcus anophagefferens* less than 35,000 cells ml^{-1} should be considered Category 1. Category 1 is based upon only a few scientific studies that document a dose-response relative to the toxicity of the alga to living organisms (Schaffner, 1999; Bricelj et al., 2001). In comparing the categories of the BTBI to conventional toxicity indices, Category 1 blooms are roughly analogous to "no observed adverse effect concentration." Category 2 blooms can be roughly compared to standard toxicity measures representing the "lowest observed effect concentration" used in standard toxicity studies. However, as brown tide concentrations increase to Category 3, with *Aureococcus* concentrations of 200,000 cells ml^{-1} or greater, the gaps in a comprehensive gradient of concentrations become apparent and it is more difficult to relate to other toxicity categories.

The BTBI is a communication tool that can be used to reduce complex information about the potential severity of brown tide blooms for the public and provide a common lexicon for managers who need to communicate information about brown tide blooms in

the northeast region. A relatively simple categorical system can relate information that can serve as a screening tool or an alert for harmful brown tide blooms. It is not assumed that the impacts listed in the index can be applied to all clones of *Aureococcus anophagefferens* or related species of *Aureococcus* or even to all natural populations of the genus. Rather they alert managers, policy makers and the public of the potential negative impacts to natural resources. Recent studies have demonstrated that different clones of *Aureococcus anophagefferens* have differing toxicities to living organisms (Bricelj et al., 2001). Because a specific toxin has not been isolated or quantified, the index is only a measure of potential effects and does not relate or predict the effect of specific brown tide concentrations. This index does not directly translate concentrations of *Aureococcus anophagefferens* into effects ranges used in toxicity studies; however, comparable units are suggested. It is important to realize that dose-response studies on the effects of *Aureococcus anophagefferens* are limited and that data collection, which supports these studies, is limited in some states. In addition, brown tide blooms are ecologically harmful to organisms regardless of toxicity (for example, shading on seagrasses (Dennison et al., 1989)).

Finally, it is assumed there may be complex ecological interactions (e.g., trophic level interactions, presence of additional algal species, etc.) that have additional impacts on natural resources under each category, which are not fully addressed in the table. While distinctions between potential impacts and duration of blooms and/or severity of blooms are not specifically addressed in this index, it is assumed that extended or prolonged blooms have a greater potential for negative impacts than blooms of shorter duration because of cumulative or shading effects.

Acknowledgments

We gratefully acknowledge several people involved in discussions with us on this manuscript and those providing review and recommendations. These include: Ted Smayda, Ph.D., URI; David Caron, Ph.D., USC; Robert Nuzzi, Ph.D., Suffolk County Department of Health Services; Patrick Dooley, NY Sea Grant; Rick Balla, USEPA; Randy Braun, USEPA, Helen Grebe, USEPA, Ann Marie Hartzig, Ph.D., ANS, Mike Ford, NOAA/ECOHAB, Peter Tango, MD DNR, Christopher Gobler, Ph.D., Southampton College, Long Island University and Alan Stern, Dr. P.H., NJDEP/DSRT.

References

Anderson, D. M., Keafer, B. A., Kulis, D. M., Waters, R. M., Nuzzi, R., 1993. An immunofluorescent survey of the brown tide chrysophyte *Aureococcus anophagefferens* along northeast coast of the United States. J. Plankton Res. 15, 563–580.

Anderson, D. M., Kulis, D. M., Cosper, E. M., 1989. Immunofluorescent detection of the brown tide organism, *Aureococcus anophagefferens*. In: E. M. Cosper, V. M. Bricelj, E. J. Carpenter (Eds.), *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, pp. 213–229. Springer-Verlag, Berlin.

Bricelj, M., 1999. Perspectives on possible factors influencing the abundance of hard clams. Workshop on Hard Clam Population Dynamics. NY Sea Grant, 2/26/99, C. G. Schlenk (Ed.), Stony Brook, NY.

Bricelj, V. M., Kuenster, S. H., 1989. Effects of the "Brown Tide" on the feeding physiology and growth of bay scallops and mussels". In: E. M. Cosper, V. M. Bricelj, E. J. Carpenter (Eds.), *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, pp. 491–510. Springer-Verlag, Berlin.

Bricelj, V. M., Lonsdale, D. J., 1997. *Aureococcus anophagefferens*: Causes and ecological consequences of brown tides in U.S. mid-Atlantic coastal waters. Limnol. Oceanogr. 42(2), 1023–1038.

Bricelj, V. M., Epp, J., Malouf, R. E., 1987. Intraspecific variation in reproductive and somatic growth cycles of bay scallops *Argopecten irradians* Mar. Ecol. Prog. Ser. 36, 123–137.

Bricelj, V. M., MacQuarrie, S. P., Schaffner, R. A., 2001. Differential effects of *Aureococcus anophagefferens* isolates ("brown tide") in unialgal and mixed suspensions on bivalve feeding. Mar. Biol. 139, 605–615.

Caron, D. A., 2001. Methodology for enumerating the causative alga of brown tides in the northeastern U.S. (Aureococcus anophagefferens). Proceedings: Brown Tide Workshop. April 6, 2001. Monmouth University, West Long Branch, NJ. NJ Marine Sciences Consortium and New Jersey Sea Grant.

Cosper, E. M., Cerami, J. C., 1996. Assessment of historical phytoplankton characteristics and bloom phenomena in the New York Harbor estuarine and New York Bight ecosystems. Final Report of the NY-NJ Harbor Estuary Program for the Hudson River Foundation. Coastal Environmental Studies, Inc.

Cosper, E. M., Lee C., Carpenter, E. J., 1990. Novel blooms in Long Island embayments: a search for the causes. In: E. Graneli, B. Sundstrom, L. Edler, D. M. Anderson (Eds.), *Toxic Marine Phytoplankton*, pp. 17–28. Elsevier, New York.

Cosper, E. M., Dennison, W. C., Carpenter, E. J., Briceli, V. M., Mitchell, J. G., Kuenster, S. H., Coleflesh, D., Dewey M., 1987. Recurrent and persistent brown tide blooms perturb coastal marine ecosystem. Estuaries 10, 284–290.

Durbin, A. G., Durbin, E. G., 1989. Effect of the "brown tide" on feeding, size and egg laying rate of adult female *Acartia tonsa*. In: E. M. Cosper, V. M. Bricelj, E. J. Carpenter (Eds.), *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, pp. 625–645. Springer-Verlag, Berlin.

Dennison, W. C., Marshall, G. J., Wigand, C., 1989. Effect of "brown tide" shading on eelgrass (*Zostera marina* L.) distributions. In: E. M. Cosper, V. M. Bricelj, E. J. Carpenter (Eds.), *Novel*

Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms, pp. 675–692. Springer-Verlag, Berlin.

Gallagher, L. F., Jr., Stoecker, D. K., Bricelj, V. M., 1989. Effects of the brown tide alga on growth, feeding physiology and locomotory behavior of scallop larvae (*Argopecten irradians*). In: E. M. Cosper, V. M. Bricelj, E. J. Carpenter (Eds.), *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, pp. 511–541. Springer-Verlag, Berlin.

Gastrich, M. D., 2000a. Harmful algal blooms in coastal waters of New Jersey. New Jersey Department of Environmental Protection. Division of Science, Research and Technology. (www.state.nj.us/dep/dsr).

Gastrich, M. D., 2000b. Brown Tide Newsletters. New Jersey Department of Environmental Protection, Division of Science, Research, and Technology, June, July 2000 www.state.nj.us/dep/dsr).

Gastrich, M. D., 2001. New Jersey Brown Tide Assessment Project. Proceedings: Brown Tide Workshop. April 6, 2001. Monmouth University, West Long Branch, NJ. New Jersey Marine Sciences Consortium and NJ Sea Grant.

Gastrich, M. D., Anderson, O. R., Cosper, E. M., 2000. Brown Tide Assessment Project in Barnegat Bay, NJ and the presence of viral-like particles in natural populations of *Aureococcus anophagefferens*. Symposium Abstract from the Symposium on Harmful Marine Algae in the U.S. Dec. 4–9, 2000. Marine Biological Laboratory, Woods Hole, MA.

Gastrich, M. D., Weinstein, M. P., Kosco, K., 2001. Brown Tide Workshop Proceedings. April 6, 2001. NJ Marine Sciences Consortium and NJ Sea Grant.

Humphries, E. M., 2001. Delaware State Program: Brown Tide. Delaware Department of Natural Resources and Environmental Control—Division of Water Resources—Ecological Assessment Branch. Proceedings: Brown Tide Workshop. April 6, 2001, Monmouth University, West Long Branch, NJ. New Jersey Marine Sciences Consortium and NJ Sea Grant.

Lonsdale, D. J., Cosper, E. M., Kim, W., Doall, M., Divadeenam, A., Jonasdottir, S. H., 1996. Food web interactions in the plankton of Long Island bays, with preliminary observations on brown tide effects. Mar. Ecol. Prog. Ser. 134, 247–263.

Mehran, R., 1996. Effects of *Aureococcus anophagefferens* on microzooplankton grazing and growth rates in the Peconic Bays system, long island, NY. M.S. Thesis. SUNY Stony Brook.

NJDEP (New Jersey Department of Environmental Protection), 1989. Annual Summary of Phytoplankton Blooms and Related Conditions in New Jersey Coastal Waters (1978–1988), Division of Watershed Management, Water Monitoring Group, 401 E. State Street, Trenton, NJ 08625.

NJDEP, 1995. Annual Summary of Phytoplankton Blooms and Related Conditions in New Jersey Coastal Waters (1978–2001). Annual Report of Phytoplankton and Conditions in New Jersey Coastal Waters. Division of Watershed Management, Water Monitoring Group, 401 E. State Street, Trenton, NJ 08625.

NJDEP, 1999. Annual Summary of Phytoplankton Blooms and Related Conditions in New Jersey Coastal Waters (1978–2001), Annual Report of Phytoplankton and Conditions in New Jersey Coastal Waters. Division of Watershed Management, Water Monitoring Group, 401 E. State Street, Trenton, NJ 08625.

Nuzzi, R., 2001. Suffolk County Department of Health Services: Summary of brown tide activities. Proceedings: Brown Tide Workshop. April 6, 2001. Monmouth University, West Long Beach, NJ. New Jersey Marine Sciences Consortium and NJSEA.

Nuzzi, R., Waters, R. M., 1989. The spatial and temporal distribution of "Brown Tide" in Eastern Long Island. In: E. M. Cosper, V. M. Bricelj, E. J. Carpenter (Eds.), *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, pp. 117–138. Springer-Verlag, Berlin.

Nuzzi, R., Olsen, P., Mahoney, J. B., Zodl, G., 1996. The first *Aureococcus anophagefferens* brown tide in New Jersey. Harmful Algae News 15, 8–9.

Probyn, T., Pitcher, G., Peinaar, R., Nuzzi, R., 2001. Brown tides and mariculture in Saldanha Bay, South Africa. Mar. Pollu. Bull. 42(5), 405–408.

Schaffner, R. A., 1999. The role of suspension feeding bivalves in the initiation and control of *Aureococcus anophagefferens* blooms. M.S. Thesis, SUNY, Stony Brook, NY.

Sieburth, J. McN., Johnson, P. W., Hargraves, P. E., 1988. Ultrastructure and ecology of *Aureococcus anophagefferens*, gen. et sp. nov. (Chrysophyceae): the dominant picoplankter during a bloom in Narragansett Bay, Rhode Island, summer 1985. J. Phycol. 24, 416–425.

Smayda, T. J., Borkman, D., 2000. Physical, chemical and biological conditions associated with the Narragansett Bay brown tide bloom. Symposium Abstract from the Symposium on Harmful Marine Algae in the U.S. Marine Biological Laboratory, Woods Hole, MA. Dec. 4–9, 2000.

Suter, G. W., 1993. *Ecological Risk Assessment*. Lewis Publishers, Boca Raton.

Tracey, G. A., 1988. Feeding reduction, reproductive failure, and mortality in the mussel, *Mytilus edulis*, during the 1985 "brown tide" in Narragansett Bay, Rhode Island. Mar. Ecol. Progr. Ser. 50, 73–81.

Wazniak, C., 2001. Maryland Brown Tide monitoring. Proceedings at Monmouth University, NJ. April 6, 2001. Monmouth University, West Long Branch, NJ. New Jersey Marine Sciences Consortium and NJ Sea Grant.