

University of Maryland, 2113 Animal Science Building College Park, Maryland 20742-2317 Telephone: 301-405-6085, FAX: 301-314-9412 E-mail: ssadams@umd.edu Web: http://www.nrac.umd.edu

Harmful Algae and Marine Aquaculture in the Northeastern United States

Daniel E. Terlizzi, University of Maryland College of Agriculture and Natural Resources, Sea Grant Extension Anthony P. Mazzacaro, University of Maryland Eastern Shore

Algae can harm aquaculture operations by reducing water quality (e.g. low dissolved oxygen; Brunson et al., 1994), interfering with feeding in bivalves (Aureococcus anophagefferens, Tracey, 1988), mechanical injury (Chaetoceros spp., Bruno et al. 1989) and marketability losses due to off-flavors (Tucker, 2000), or toxicity. Toxic algae result in major losses in aquaculture causing mortality in finfish and shellfish operations as a consequence of: 1) anoxic or hypoxic conditions resulting from algal biomass, 2) mechanical damage to fish gills, and 3) toxins. Toxic algae also pose a threat to aquaculture through human health problems associated with toxin accumulation in seafood. This fact sheet considers toxic algae causing fish and shellfish mortality in saltwater aquaculture systems that may be a concern in the northeastern United States. Freshwater algal concerns in ponds were recently described by Rodgers (2008).

Algae blooms and conditions for toxin formation

Algae blooms are natural events of increased algal cell numbers, due to increased growth supported by adequate resources and environmental conditions. The resource quantity and quality necessary to support a bloom event varies with species but generally elevated nutrient levels coupled with adequate light can cause bloom development. Salinity is an important factor since it can determine the types of bloom species, especially in estuarine systems ranging from cyanobacteria typical of low salinity to estuarine and marine dinoflagellates. There is growing concern that harmful algal blooms, or HABS, are increasing on a global scale (Shumway, 1990; Hallegraeff, 1993) and that this may be a result of increasing eutrophication of coastal waters (Anderson et al. 2002). Hallegraeff (1993) suggested that increased HAB frequency may also reflect increased monitoring. Fewer than 5% of the known algal species are ichthyotoxic but toxic algal events can be dramatic and have resulted in substantial losses to the aquaculture industry world-wide. In many cases fish mortality in situ has been attributed to water quality problems like low dissolved oxygen but increasingly it is found that smaller less conspicuous toxic dinoflagellates (e.g. Karlodinium) are responsible.

Hallegraeff (1993) also pointed out that aquaculture systems may act as sentinels providing an early detection warning system for HABS. A bloom can result in mortality without toxin production; however, a number of phytoplankton species can cause fish or shellfish mortality through production of toxins. Algal toxins include a variety a chemical structures with different mechanisms of action (Landsberg, 2002). Several hypotheses have been proposed for the roles of toxins produced by algae including self defense and food capture in species that are capable of "eating" other algal cells (Graneli and Hansen, 2008). From a management perspective it is important to realize that toxin production is generally associated with slowing of bloom growth in response to resource limitation. Aquaculture systems, as Hallegraeff (1993) noted, can become bioassay systems for the detection of harmful algal species. The combination of high nutrients, high fish biomass and introduction of natural phytoplankton communities can "tease out" phytoplankton species that may have been in low abundance, or even undetected previously. This was demonstrated recently in the Mid-Atlantic region in a hybrid striped bass (HSB) production facility where a series of blooms of a species thought to be a non-toxic dinoflagellate, G. estuariale, was determined to be the toxic dinoflagellate G. galatheanum (now Karlodinium veneficum) (Terlizzi et al. 2000; Terlizzi, 2006; Deeds et al., 2002). Harmful algae in freshwater aquaculture systems are better understood than those in saltwater aquaculture although it is fair to state that understanding of HABS and HAB management is in early development in both systems.

HABs of freshwater aquaculture systems most commonly are cyanobacteria (blue green algae) and euglenoids (Rodgers, 2008). In saltwater aquaculture systems, which can include brackish water to full strength marine salinities, toxin producing HABs may include cyanobacteria and euglenoids at the lower salinities, along with Prymnesium parvum (a golden brown flagellate classified as a haptophyte), diatoms and dinoflagellates. Besides toxin production, a number of saltwater phytoplankton have been associated with mechanical damage to fish, both natural populations and cultured species. Mechanical damage is a result of morphological features of phytoplankton, such as sharp silica spines, causing injury or irritation of fish tissue, particularly gills. Examples include the diatoms, Chaetoceros spp., Corethron spp. and Leptocylindrus spp. In addition, the silicoflagellate Dictyocha speculum has caused mortality of Atlantic salmon in aquaculture systems through gill irritation by the sharp siliceous skeleton of the taxon. The brown tide pelagophytes Aureococcus anophagefferens and Aureoumbra lagunensis interfere with zooplankton and shellfish through both mechanical and toxic effects.

The following are brief descriptions of some of the HAB species of concern to aquaculture in the northeastern U.S., by taxonomic groups.

Diatoms

Diatom genera common in the Northeast have been associated with mortality or inhibition of copepods and other grazers (a food web concern) but may also indicate risks to aquaculture production. The centric diatom genera *Thalassiosira*, *Chaetoceros*, *Cyclotella*, and *Ditylum* are widely distributed and of possible concern (Landsberg, 2002). Fish mortality due to toxic effects of diatoms is not well understood. The genus *Rhizosolenia*, common in the northeastern U. S., has been associated with shellfish mortality in Australia, but this diatom genus has not been associated with mortalities in the U.S. Mechanical injury caused by siliceous spines of centric diatom genera *Chaetoceros* and *Rhizosolenia* appears to be the greater concern, although this may change with increased development of aquaculture.

Pseudonitzschia multiseries produce the neurotoxin domoic acid (DA) that has caused human illness and mortality from consumption of blue mussels. Pseudonitzschia spp. are widely distributed and abundant in the northeastern U.S. and areas with significant shellfish production. Direct impacts of DA from *Pseudonitzschia spp*. on aquaculture production are not as clear but impacts on rotifers, copepods, shellfish including Pacific oysters and finfish (Californian anchovies and sardines) have been observed.



Pseudonitzchia spp., from California Department of Health.

Dinoflagellates

Alexandrium spp.



Alexandrium tamarense Strain PE1V

Alexandrium tamarense Image: Provasoli-Guillard National Center for Culture of Marine Phytoplankton. The Marine Biological Laboratory. Alexandrium spp. represents a cosmopolitan genus containing species that produce saxitoxin causing paralytic shellfish poisoning (PSP) in humans. This genus (A. tamarense and A. catanella) has been associated with fish and shellfish mortality in aquaculture systems worldwide (Ogata and Kodama, 1986; Mortensen, 1985; Lush and Hallegraeff, 1996). An extensive Alexandrium bloom in coastal areas of Maine, New Hampshire and Massachusetts resulted in the accumulation of PSPinducing toxins in lobsters. In 2009 northeast winds concentrated toxic Alexandrium in coastal Maine shellfish production areas.



Procentrum minimum. Image: Algae Base, www.algaebase.org

Prorocentrum minimum

Prorocentrum minimum is a cosmopolitan species that has been associated with shellfish mortality through toxin production and fish mortality through oxygen depletion during extensive blooms. At high densities it interferes with feeding, spawning and larval development in the eastern oyster *Crassostrea virginica* (Luckenbach *et al.*, 1993; Wikfors and Smolowitz, 1995; Wikfors *et al.* 1993). A dense spring bloom of *P. minimum* was associated with oyster mortality in an aquaculture facility in a Chesapeake Bay tributary but it was not clear if this was due to toxin production or anoxia (D. Terlizzi, unpublished).



Prorocentrum lima (Ehrenberg) Dodge. Image: Algae Base www.algaebase.org



Karlodinium veneficum. Image: Provasoli-Guillard National Center for Culture of Marine Phytoplankton.

Prorocentrum lima

P. lima may be a concern in New England, as it has been found in several near-shore environments associated with shellfish communities. As a producer of okadaic acid, it can produce diarrhetic shellfish poisoning (DSP) in humans consuming local shellfish. Maranda *et al.* (2007) has summarized recent intoxications in the region. Although limited uptake of okadaic acid was observed in shellfish, its presence in shellfish argues for increased knowledge of this possible human health issue.

Karlodinium veneficum

Karlodinium veneficum is the first toxic dinoflagellate confirmed from the Chesapeake Bay area. It was discovered following large scale mortality of HSB at a fish farm in Maryland. Initially, mortality was attributed to *Pfiesteria piscicida* which was present at low cell densities. However, the dominant dinoflagellate involved in the mortality was identified as *Gyrodinium galatheanum* (now called *Karlodinium veneficum*) suggesting *Pfiesteria* was not responsible (Terlizzi *et al.*, 2000). Toxicity of *Karlodinium veneficum* was confirmed in laboratory studies (Deeds *et al.*, 2002). *Karlodinium* is responsible for fish deaths worldwide *in situ* and in aquaculture



Cochlodinium polykrikoides bloom. Photo: WHOI



Pfisteria piscicida. Photo: Michael A. Mallin, Center for Marine Science, University of North Carolina at Wilmington.

systems. *K. veneficum* is toxic to oyster embryos, larvae, juveniles and reduces feeding in adults and may be a concern in recovery of the Chesapeake oyster fishery (Glibert *et al.* 2007; Brownlee *et al.*, 2008; Stoecker *et al.*, 2008). The discovery of this small dinoflagellate is a good recent example of the cautionary remarks of Halle-graeff (1993) that aquaculture facilities may act inadvertently as bioassay systems for the detection of HABs.

Cochlodinium polykrikoides

C. polykrikoides and related species have been associated with mortality of finfish and/or shellfish in U.S. coastal waters and internationally. Recent blooms of *C. polykrikoides* have been toxic to fish and shellfish (Mulholland *et al.*, 2009). Different toxic properties have been associated with *C. polykrikoides* fractions including neurotoxic and hemolytic activies. Paralytic shellfish poisoning toxins have also been detected (Onoue and Nozawa 1985; Onoue and Nozawa, 1989). A *Cochlodinium* bloom precipitated shellfish bed closure in the Potomac River.

Pfiesteria piscicida

This small, primarily heterotrophic dinoflagellate was thought to be the cause of extensive fish mortality in pond based HSB aquaculture systems in North Carolina. To reduce fish death HSB producers were forced to switch from estuarine water to deep fresh water wells (R.Hodson, personal communication). Because *Pfiesteria* is a small dinoflagellate like *Karlodinium veneficum* and because *Karlodinium* has been associated with large mortalities in North Carolina, there has been speculation that *Karlodinium* may have been responsible for the pond HSB aquaculture mortalities observed. *Pfiesteria* was thought to be responsible for fish kills in the Chesapeake Bay precipitating the "*Pfiesteria* hysteria" of 1997 but difficulties inducing toxicity suggested that other

co-occurring dinoflagellates like *Karlodinium* might have been responsible (Terlizzi, 2000).

Flagellates (Prymnesiophytes)

Prymnesium parvum is golden-brown brackish water flagellate that is a cosmopolitan concern in aquaculture systems. Recent extensive blooms have been reported in Texas brackish water lakes including aquaculture systems for striped bass with substantial economic losses at millions of dollars annually (Sunda et al., 2006). P. parvum is a euryhaline species but dense blooms associated with fish mortality are generally in brackish waters. Three distinct toxic activities are produced by P. parvum: ichthyotoxicity, cytotoxicity and hemolysis (Ulitzer and Shilo, 1966, 1970; Ulitzer, 1973). Collectively termed prymnesins, they alter membrane permeability, which can rapidly interfere with gill function in fish (Shilo, 1971). P. parvum toxicity has been linked to nutrient (N or P) limitation which can occur at high bloom densities (Johansson and Graneli, 1999). In contrast with the toxins produced by many other harmful algal species, there are no reported toxic effects on humans or vertebrate species exposed to P. parvum.



Prymnesium parvum. Image: John LaClaire, Texas Parks and Wildlife

Detection and Management

If we consider harmful algal management in aquaculture analogous to weed management in agronomic systems, then "weed" management in aquaculture is in its infancy. Aquaculture operations in the northeastern U.S. range from open water finfish cage culture and shellfish beds to natural water impoundments for finfish and shellfish cultivation. In both cases, aquaculture facilities can alter the structure of phytoplankton



Fish kill in Choptak River, caused by Harmful Algal Bloom (HAB). Photo: Adrian Jones, University of Maryland Center for Environmental Science.

communities, through nutrient addition in particular, and produce HABs. In pond aquaculture HABs may result from introduction of harmful species at high densities during "topping up" or by introduction of harmful species at low cell densities that are selectively stimulated by the environmental conditions of the ponds.

HAB introduction from natural waters can be prevented through ozonation and filtration at the point of intake but these are expensive options and not always practical. At the HSB facility where K. veneficum was first observed to have toxic effects on fish in the Chesapeake region, installation of ozone injectors at the intake point of estuarine water reduced risks (Deeds et al. 2004). Blooms posing a risk to aquaculture facilities in natural waters are a major concern since management techniques like clay flocculation are just developing which reinforces the need for careful site selection. Ideally site selection for reducing risk of HABs in aquaculture will include: 1) hydrographic assessment to avoid risk of bloom transport by water movement or nutrient introduction, 2) assessment of nutrient availability, 3) analysis of phytoplankton community structure and presence of potentially harmful species, and 4) The presence of cysts of HAB species in sediments (Shumway, 1990).

Aquaculture systems in natural waters can be exposed to HABs through movement of naturally occurring blooms or through selective stimulation of HAB species present at low cell densities. HABs developing within ponds may be managed through chemical control (copper sulfate, potassium permanganate) or less directly through mixing and shading by dyes. Whether bloom development is in ponds or in natural waters the first concern is detection. Regular monitoring is essential because many harmful algal blooms develop rapidly due to high growth rates or cyst recruitment from sediments.

Routine microscopic examination of water samples weekly or even more frequently during warmer months is warranted. Species-specific assays have been developed for some of the more common HAB species, e.g., a monoclonal antibody procedure developed by West et al. (2006) is used to quantify P. parvum. The producer should be alert to slight changes in water color and fish behavior, especially changes in feeding behavior or symptoms of oxygen stress. Kim (2008) summarizes management techniques for HABs along with monitoring and management strategies to reduce HAB frequency (e.g., water circulation and nutrient remediation); he discusses direct controls including physical (centrifugation, ultrasound), biological (grazing, parasitic dinoflagellates, viruses) and chemical methods (surfactants, oxidants, copper sulfate). Chemical bloom treatments need to be carefully considered. Copper treatments have been used successfully in managing algal blooms in brackish water ponds; however, cell lysis from copper treatment can release intracellular toxins and result in rapid and extensive mortality. This is how the toxic activity and toxin of Karlodinium veneficum was discovered (Terlizzi et al., 2000, Deeds et al., 2002). Potassium permanganate was effective and safe for the management of a series of K. veneficum blooms (1996-2000) that occurred during at Hyrock fish farm, an HSB producing facility using estuarine Chesapeake Bay waters in pond culture (Deeds et al., 2004).

The haptophyte *Prymnesium parvum* has been the subject of a number of investigations concerning control in aquaculture systems beginning in Israel in the 1940s (Reich and Aschner, 1947). Guo *et al.* (1996) examined the use of ammonium sulfate, copper sulfate, mud, reduced salinity and manure addition to control P. parvum and concluded that ammonium sulfate was efficient, economical and safe. In the U.S. effective control procedures have been described for *P. parvum* based on a combination of treatments with unionized ammonia through treatment with ammonium sulfate and copper sulfate (Barkoh *et al.* 2003). Both treatments require particular caution due to toxicity to non-target organisms and food web disruption.

Barley straw has been suggested as a method for algae management in Britain for several decades (O h Uallachain and Fenton, 2010) although research in the U.S. suggests it is not reliable (e.g. Barkoh *et al.* 2008, with *P. parvum*). Several studies have shown that barley straw extracts can be inhibitory to some species while neutral or stimulatory to others (Martin and Ridge,1999; Brownlee *et al.*, 2003; Ferrier *et al.*, 2005). Terlizzi *et al.* (2002) examined sensitivity to barley straw in several potentially problematic marine estuarine dinoflagellate species and found similar stimulatory and inhibitory effects. *K. veneficum* growth was inhibited by barley straw extract while *P. minimum* was stimulated. An inhibitor class of polyphenolics was partially characterized by Waybright *et al.* (2009), reinforcing the view that barley straw produces algal inhibitors that may be useful in treatment of specific blooms.

Promising results have been noted for clay flocculation and removal of algae blooms, in freshwater (cyanobacteria) and marine (e.g., *Karenia brevis*) systems, including some laboratory work with *Alexandrium* (e.g., see Sengco and Sellner, 2008). However, routine adoption in the U.S. has been difficult due to public reluctance for direct intervention in open waters (M. Sengco, personal communication).

Acknowledgments



United States Department of Agriculture

National Institute of Food and Agriculture This work was conducted with the support of the Northeastern Regional Aquaculture Center, through grant number 2006-38500-17605 from the National Institute of Food and Agriculture (NIFA), U.S. Department of Agriculture. We thank Sarah Kenney for her assistance with preparation of the manuscript and Peg Van Patten for her editorial guidance. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the U.S. Department of Agriculture.

References

- Anderson, D.M., Glibert, P.M., Burkholder, J.M. 2002. Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. *Estuaries*. 25(4b):704-726.
- Barkoh, A., Paret, J., Lyon, D. Begley, D., Smith, D., Schlecte, J. 2008. Evaluation of barley straw and a commercial probiotic for controlling *Prymnesium parvum* in fish production ponds. *North American Journal of Aquaculture* 70:80-91
- Barkoh, A., Smith, D.G., Shlecte, J.W. 2003. An effective minimum concentration of un-ionized ammonia nitrogen for controlling *Prymnesium parvum*. North American Journal of Aquaculture 65:220-225.
- Brownlee, E.F., Sellner, K.G., Sellner S.G. 2003. The effects of barley straw (*Hordeum vulgare*) on freshwater and brackish phytoplankton and cyanobacteria. *Journal of Applied Phycology*. 15:525-531.

- Brownlee, E.F., Sellner, S.G., Sellner, K.G., Nonogaki,
 H., Adolf, J.E., T.R., Bachvaroff, T.R., Place, A.R.
 2008. Responses of *Crassostrea virginica* (Gmelin)
 and *C. ariakensis* (Fujita) to bloom-forming phytoplankton including ichthyotoxic *Karlodinium veneficum* (Ballantine). *Journal of Shellfish Research* 27:581-591.
- Bruno, D.W., Dear, G., Seaton, D.D. 1989. Mortality associated with phytoplankton blooms among farmed Atlantic Salmon, *Salmo salar L.*, in Scotland. *Aquaculture* 78:217-222.
- Brunson, M.W., Lutz, C.G., Durborow, R.M. 1994. Algae blooms in commercial fish production ponds. SRAC Publication No. 466.
- Deeds, J.R., Terlizzi, D.E., Adolf, J.E., Stoecker, D.K., Place, A.R. 2002. Toxic activity from cultures of *Gyrodinium galatheanum* (Dinophyceae)—a dinoflagellate associated with fish mortalities in an estuarine aquaculture facility. *Harmful Algae* 1:169-189.
- Deeds, J.R., Mazzacaro A.P., Terlizzi, D.E., Place A.R. 2004. Treatment options for the control of the ichthyotoxic dinoflagellate *Karlodinium micrum* in an estuarine aquaculture facility: a case study. Proceedings of the Second International Conference on Harmful Algae Management and Mitigation, Nov. 12-16, Quingdao, China. In Hall, S., Etheridge, S., Anderson, D., Kleindinst, J., Zhu, M., and Zou, Y. (Eds.) *Harmful Algae Management and Mitigation. Asia-Pacific Economic Cooperation* (Singapore) APEC Publication #204-MR-04.2:177-181.
- Ferrier, M.D., Butler, B.R., Terlizzi, D.E., Lacouture, R.V. 2005. The Effects of Barley Straw (*Hordeum vulgare*) on the Growth of Freshwater Algae. *Bioresource Technology* 96:1788-1795.
- Glibert, P.M., Alexander, J., Merritt, D.W., North, E.W., Stoecker, D.K. 2007. Harmful algae pose additional challenges for oyster restoration: impacts of the harmful algae *Karlodinium veneficum* and *Prorocentrum minimum* on early life stages of the oysters *Crassostrea virginica* and *Crassostrea ariakensis*. *Journal of Shellfish Research* 26:919-925.
- Glibert, P.M., Terlizzi, D.E. 1999. Cooccurrence of elevated urea levels and dinoflagellate blooms in temperate estuarine aquaculture ponds. *Applied and Environmental Microbiology* 65(12):5594-5596.

- Graneli, E., Hansen, J. 2008. Allelopathy in harmful algae: a mechanism to compete for resources. In: Graneli, E., and Hansen, J. [eds.]. 2008. *Ecology* of Harmful Algae. Ecological Studies 189. Springer New York:189-199.
- Hallegraeff, G.M. 1993. A review of harmful algal blooms and their apparent global increase. *Phycologia* 32: 79-99.
- Johansson, N., Graneli, E. 1999. Influence of different nutrient conditions on cell density, chemical composition and toxicity of *Prymnesium parvum* (Haptophyta) in semicontinuous cultures. *Journal* of *Experimental Marine Biology and Ecology* 239:243-258.
- Kim, H.G. 2008. Mitigation and control of HABs. In: Graneli, E., and Hansen, J. [eds.]. 2008. *Ecology* of Harmful Algae. Ecological Studies 189. Springer New York, pp.327-338.
- Landsburg, J.H. 2002. The effects of harmful algal blooms on aquatic organisms. *Reviews in Fisheries Science* 10:113-390.
- Lush, G., Hallegraeff, G. 1996. High toxicity of the red tide dinoflagellate *Alexandrium minutum* to the brine shrimp *Artemia salina*. In: Yasumoto, T., Oshima, Y. and Fukuyo Y. [eds]. *Harmful and Toxic Algal Blooms*, pp. 389-392. Paris: Intergovernmental Oceanographic Commission of UNESCO. 1996.
- Maranda, L., Corwin, S., Dover, S. and Morton, S. 2007. *Prorocentrum lima* (Dinophyceae) in northeastern USA coastal waters—II: toxin load in the epibiota and in shellfish. *Harmful Algae* 6:632-641.
- Martin, D. Ridge, I. 1999. The relative sensitivity of algae to decomposing barley straw. *Journal of Applied Phycology* 11:285-291.
- Mortenson, A. 1985. Massive fish mortalities in the Faroe Islands caused by a *Gonyaulax excavate* red tide. In: Anderson, D.M., White, A., and Baden, D. [eds]. *Toxic Dinoflagellates*. New York: Elsevier. 1985. pp. 165-170.
- Mulholland, M. R., Morse, R.E., Boneillo, G.E., Bernhardt, P.W., Filllippino, K.C., Procise, L.A., Blanco-Garcia, J.L., Marshall, H.G., Egerton, T.A., Hunley, W.S., Moore, K.A., Berry, D.L., Gobler, C.J. 2009. Understanding causes and impacts of the dinoflagellate, *Cochlodinium polykrikoides*, blooms in the Chesapeake Bay. *Estuaries and Coasts* 32:734-747.

- Luckenbach, M.W., Sellner, K.G., Shumway, S.E., Greene, K., 1993. Effects of two bloom-forming dinoflagellates, *Prorocentrum minimum* and *Gyrodinium uncatenum*, on the growth and survival of the eastern oyster *Crassostrea virginica* (Gmelin, 1791). *Journal of Shellfish Research* 12:411-415.
- Ogata, T., and Kodama, M. 1986. Ichthyotoxicity found in cultured media of *Protogonyaulax* spp. *Marine Biology* 92:31-34.
- Onoue, Y., Nozawa, K. 1989. Separation of toxins from harmful red tides occurring along the coast of Kagoshima prefecture. In: Okaichi,T., Anderson, D.M., and Nemoto, T. [eds]. *Red Tides, Biology, Environmental Science and Technology*, pp. 371-374. New York: Elsevier 1989.
- O hUallachain, D., Fenton, O. 2010. Barley (*Hordeum vulgare*)-induced growth inhibition of algae: a review. *Journal of Applied Phycology* 22:651-658.
- Onoue, Y., Nozawa, K. 1989. Zinc bound PSP toxins separated from Cochlodinium red tide. In: Natori, S., Hashimoto, K., and Ueno, Y. [eds]. *Mycotoxins* and and Phycotoxins '88, pp. 359-366. Amsterdam: Elsevier 1989.
- Reich K., Aschner, M. 1947. Mass development and control of the phytoflagellate *Prymnesium parvum* in fish ponds in Palestine. *Palestine Journal of Botany*, Jerusalem 4:14-23.
- Rodgers, J.H. 2008. Algal toxins in pond aquaculture. SRAC Publication No. 4605
- Sengco, M.R., Sellner, K.G. 2008. HABs and clay flocculation: Review and discussion of studies, impacts, and future directions. Pages 158-161. In: Ø. Moestrup & H. Enevoldsen (eds.), Proc. of the 12th International Symposium on Harmful Algae. ISSHA & IOC-UNESCO, Copenhagen.
- Shilo, M. 1971. Toxins of Chrysophyceae. In: Kadis, S., Ciegler, A., and Ajl, J.J. [eds]. *Microbial Toxins* Vol 7. New York: Academic Press. pp. 67-103.
- Shumway, S.E. 1990. A review of the effects of algal blooms on shellfish and aquaculture. *Journal of the World Aquaculture Society* 21:65-104.
- Stoecker, D., Adolf, J., Place, A. Glibert, P., Meritt, D. 2008. Effects of the dinoflagellates *Karlodinium veneficum* and *Prorocentrum minimum* on early life history stages of the eastern oyster (*Crassostrea virginica*). *Marine Biology* 154:81-90.

- Sunda, W.G., Graneli, E., Gobler, C.J. 2006. Positive feedback and the development and persistence of ecosystem disruptive algal blooms. *Journal of Phycology* 42: 963-974.
- Terlizzi, D.E. 2006. Water quality, agriculture and *Pfiesteria* in the Chesapeake Bay: the extension bridge over troubled waters. *Journal of Extension* 44: online <u>http://www.joe.org/joe/2006october/a3.shtml</u>.
- Terlizzi, D., Stoecker, D., Glibert, P. 2000. *Gyrodinium* galatheanum: a threat to estuarine aquaculture. Responsible Aquaculture for the New Millenium. Aqua 2000, May 2-6, Nice, France.
- Terlizzi, D.E., Ferrier, M.D., Armbrester, E.A., Anlauf, K.A. 2002. Inhibition of dinoflagellate growth by extracts of barley straw (*Hordeum vulgare*). *Journal* of Applied Phycology 14: 275-280.
- Tracey, G.A., 1988. Feeding reduction, reproductive failure, and mortality in *Mytilis edulis* during the 1985 'brown tide' in Narragansett Bay, Rhode Island. *Marine Ecology Progress Series* 50: 73-81
- Tucker, C.S. 2000. Off flavor problems in aquaculture. *Reviews in Fisheries Science* 8:45-88.
- Ulitzer, S. Shilo, M. 1964. A sensitive assay system for the determination of the ichthyotoxicity of *Prymnesium parvum. General Microbiology* 36:161-169.
- Ulitzer,S. 1973 The amphiphatic nature of *Prymnesium parvum* hemolysin. Biochemica et Biophysica Acta 298: 673-679.
- Ulitzer, S. Shilo, M. 1966. Mode of action of *Prymnesium parvum* ichthyotoxin. *Journal of Protozoology* 13:332-336.
- Waybright, T.J., Terlizzi, D.E., Ferrier, M.D. 2009. Chemical characterization of the algistatic fraction of barley straw (*Hordeum vulgare*) inhibiting *Microcystis aerugiunosa*. *Journal of Applied Phycology* 21:333-340.
- West, N.J., Bacchieri, R., Hansen, G., Tomas, C., Lebaron, P., Moreau, H. 2006. Rapid quantification of the toxic alga *Prymnesium parvum* in natural samples by the use of a specific monoclonal antibody and solid-phase cytometry. *Applied and Environmental Microbiology* 72:860-868.
- Wikfors, G.H., Smolowitz, R.M. 1995. Experimental and histological studies of four life-history stages of the eastern oyster, *Crassostrea virginica* exposed to a cultured strain of the dinoflagellate *Prorocentrum minimum*. *The Biological Bulletin* 188:313-328.

Wikfors, G.H., Smolowitz, R.M., Smith, B.C. 1993. Effects of a *Prorocentrum* isolate upon the oyster, *Crassostrea virginica*: a study of three life-history stages. *Journal of Shellfish Research* 12:114-115.