Toxic Algae, Fish Kills and Fish Disease

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Toxin-producing algae are becoming an increasingly serious worldwide problem in both aquaculture and fisheries populations. They affect the gamut of aquatic taxa, from marine mammals to finfish to shellfish. The prevalence of toxic algae blooms appears to be dramatically increasing worldwide and in addition, the magnitude (i.e., severity) of the blooms appears to be increasing. New types of toxic algae as well as algae which were never before known to produce toxins are also being reported. While acute mortalities (eg., kills) due to toxic algae have been the focus of attention for some time, there is now evidence that exposure of aquatic animals to toxin-producing algae can lead to serious sublethal effects, including predisposing these populations to various infectious diseases. These findings indicate that the potential impacts of noxious algae blooms may extend well beyond our traditional concepts of risk from toxic algae exposure and may play as yet undefined but crucial roles in the health of both natural and cultured aquatic populations. One specific toxic dinoflagellate, *Pfiesteria piscicida*, is used to illustrate this point.

Key words: *Pfiesteria piscicida*, dinoflagellate, toxic algae, risk factor, environment

There has been a tremendous amount of work devoted to the examination of various types of infectious diseases and their effects on aquatic animals. Relatively little is known about how the environment influences the development of such diseases, although it is increasingly apparent that the pathogenicity of infectious agents is greatly influenced by many environmental circumstances. Among the newly emerging environmental risk factors which must now be considered as players in this scenario are toxic algae.

The Impact of Toxic Algae in Aquaculture

Toxin-producing algae are becoming an increasingly serious problem in both aquaculture and fisheries populations. Not only has the severity or magnitude of these blooms appeared to increase in recent years, but the number of geographic locations experiencing toxic algal blooms has also increased (Fig. 1). Toxic algae blooms are a worldwide problem affecting aquatic populations in both warm water and cold water environments. The great majority of problems have occurred in near-coastal

marine ecosystems and thus may have the greatest potential impact on cage and net pen culture. They may also be a threat to culturists obtaining water from sites prone to develop toxic algae blooms (eg., land-based tank systems). And in some cases, the introduction of toxic algae into a closed aquaculture system may result in devastating effects (see below).

Increased eutrophication or nutrient enrichment has often been correlated with increased prevalence of many toxic algae blooms (Smayda, 1990; 1992), but there appear to be other important risk factors besides simply increased nitrogen or phosphorus which are essential for development of a bloom. The problem of toxic algae is a cogent lesson in how the success of marine aquaculture is so heavily dependent upon a healthy and balanced natural environment and that aquaculturists have a vested interest in assuring that the marine environment is not degraded.

Many different toxic algae have been implicated in fish kills (Table 1), although in most cases the precise toxins or mechanism of toxicity is unclear. Nonetheless, many different types of toxins have been isolated from various algae and many of these are ichthyotoxic. Neurotoxins are especially common. Clinical signs of algal neurotoxicity include disorientation, loss of equilibrium, and sporadic hyperactivity. Other algae

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Fig. 1. Global distribution of kills in wild and cultured fish associated with noxious phytoplankton (modified from Sundstrom *et al.*, 1990).

mechanically obstruct or damage the gills, causing hypoxia (Kent, 1992).

Dinoflagellates represent the predominant toxin-producing algae. Many dinoflagellates have been implicated or suspected in fish kills. The red tide dinoflagellate (*Gymnodinium breve*) causes mass mortalities of fish and invertebrates in states bordering the Gulf of Mexico (Steidinger and Baden, 1984). Some dinoflagellate toxins are transferred up the food chain (eg., *Alexandrium*) and have caused mortalities in wild fish (eg., Atlantic herring *Clupea harengus*) that consume tainted zooplankton along the northwest Atlantic coast of the United States (White, 1981).

Other algal groups associated with toxicity include the prymnesiophytes and diatoms. The prymnesiophyte *Prymnesium parvum* causes mortality in brackish and marine pond fish (eg., mullet *Mugil* spp.) in Europe and the Middle East (Shilo, 1981). Diatoms in the genus *Chaetoceros* have been associated with mortality in seawater-cultured salmonids. The spines of the alga apparently cause it to become lodged on or in the gills. Diatoms may become embedded in gill tissue, inciting a foreign body reaction. Epithelial hyperplasia causes hypoxia. In some cases, hyperactive mucus production appears to be primarily responsible for the hypoxia

(Rensel, 1993). Various algae have been associated with mortalities in Japan (Lassus *et al.*, 1995). Other algae have been less commonly associated with ichthyotoxicity (Table 1), although there is considerable speculation about possible sublethal effects (Landsberg, 1995; 1996).

The Role of *Pfiesteria piscicida* in Fish Kills and Fish Disease

Traditionally, acute mortality (i.e., fish kills) has been the extent of our concern about the effects of toxic algae on aquatic populations. However, we are beginning to realize that the impact of toxic algae blooms extends well beyond their ability to simply kill fish acutely. This point is particularly well-illustrated with a toxic dinoflagellate which has caused considerable concern in the western Atlantic region of the U.S. This organism, *Pfiesteria piscicida*, represents a new genus and family of dinoflagellates (Pfiesteriaceae) in the Order Dinamoebales (Steidinger *et al.*, 1996).

Pfiesteria piscicida was discovered in the late 1980's (Smith *et al.*, 1988) and has subsequently been associated with fish kills in the two largest estuarine ecosystems in the United States, the Albemarle-Pamlico and

Table 1. Algae associated with toxicoses to fish (modified from Noga, 1996)

Taxonomic Group
Dinoflagellates (Class Dinophyceae)
<i>Alexandrium excavatum</i> *
<i>Alexandrium monilata</i>
<i>Alexandrium polyedra</i>
<i>Alexandrium spinifera</i>
<i>Alexandrium tamarensis</i>
<i>Alexandrium veneticum</i>
<i>Amphidinium carterae</i>
<i>Amphidinium klebsii</i>
<i>Amphidinium rhyncephalum</i>
<i>Gambierdiscus toxicus</i>
<i>Gymnodinium breve</i>
<i>Gymnodinium veneticum</i>
<i>Gyrodinium aureolum</i>
<i>Noctiluca miliaris</i>
<i>Peridinium polonicum</i> (F)
<i>Peridiniopsis</i> -like
<i>Pfiesteria piscicida</i>
<i>Pfiesteria</i> sp.
<i>Prorocentrum balticum</i>
<i>Prorocentrum concavum</i>
<i>Pyrodinium bahamense</i> var. <i>compressa</i>
Cyanobacteria ("Blue green algae")
<i>Anabaena flos-aquae</i> (F)
<i>Aphanizomenon flos-aquae</i> (F)
<i>Microcystis aeruginosa</i> (F)
<i>Oscillatoria agardhii</i> (F)
<i>Oscillatoria rubescens</i> (F)
<i>Schizothrix calcicola</i>
Yellow-green Algae (Class Chrysophyceae)
<i>Ochromonas danicum</i> (F)
<i>Ochromonas malhamensis</i> (F)
<i>Ochromonas minuta</i> (F)
Prymnesiophytes (Class Prymnesiophyceae)
<i>Chrysochromulina polylepis</i>
<i>Prymnesium parvum</i>
<i>Prymnesium calathiferum</i>
Rhaphidophyceans (Class Rhaphidophyceae)
<i>Chattonella antiqua</i>
<i>Heterosigma akashiwo</i>
Diatoms (Class Bacillariophyceae)
<i>Chaetoceros convolutus</i>
<i>Chaetoceros concavicornus</i>
<i>Corethron</i> sp.
Green Algae (Class Chlorophyceae)
<i>Chaetomorpha minima</i>

All marine or estuarine organisms, unless noted by "F" (freshwater).

Data from Steidinger and Baden (1984), Davin *et al.* (1988), Kent (1992), Chang *et al.* (1990) and Steidinger *et al.* (1997).

Note that many of the listed algae have only been associated with fish kills and have not been proven to be the cause of mortalities. The pathogenesis of most noxious algae in causing fish morbidity/mortality is uncertain.

**Alexandrium* species were previously classified as *Gonyaulax* or *Protogonyaulax*.

Chesapeake Bay estuaries (Burkholder *et al.*, 1992, 1995; Steidinger *et al.*, 1997). It has also caused serious mortality in both aquarium and pond aquaculture systems (Noga *et al.*, 1993; Burkholder *et al.*, 1992). Another *Pfiesteria* species has also been isolated from a marine aquarium in Florida, although the geographic origin of the isolate is uncertain (Landsberg *et al.*, 1995). While *P. piscicida* was also initially reported from other estuarine ecosystems along the U.S. western Atlantic coast (Burkholder *et al.*, 1995), it now appears that there are different morphologically similar species in this taxon, and the toxicity of these various organisms requires further research (Steidinger *et al.*, 1997).

Pfiesteria piscicida has a number of intriguing characteristics. One of the most fascinating, which also lead to its discovery, is that it is stimulated to bloom and produce its toxins in the presence of live fish (Smith *et al.*, 1988) (Fig. 2). While *P. piscicida* can rapidly kill fish (within minutes) when vigorously blooming, sublethal exposure results in a number of dramatic effects. Among the most striking of these changes is massive skin damage due to epithelial erosion. This damage is associated with epidermal edema and can result in virtually complete denuding of the skin within 24 h exposure to a toxin level that kills fish within about 48 h (Noga *et al.*, 1996). Thus, sublethal exposure of fish to *P. piscicida* results in acute suppression of local defenses, since the skin epithelium is a major source of defensive

Fig. 2. *Pfiesteria piscicida* is stimulated to bloom in the presence of live fish. Four fish were added to an aquarium at time 0 and the aquarium was simultaneously inoculated with a small number (1000) of *P. piscicida* cells. By day 13, the algae began to bloom, and it began to kill fish by day 15 (each arrowhead represents one fish mortality). When all the fish died, the algae was no longer stimulated to bloom and subsequently became dormant (from Smith *et al.*, 1988).

chemicals, including lysozyme, complement and antibody.

This primary skin damage then leads to a number of secondary effects, including severely impaired osmoregulation (due to loss of the epithelial barrier) and secondary microbial infections, including opportunistic bacteria and fungi, which result in shallow to deep skin ulcers. These skin lesions are clinicopathologically similar to certain skin ulcers which have plagued estuarine fishery populations of the U.S. western Atlantic for a number of years, among the most common of which is ulcerative mycosis, a mixed fungal-bacterial infection that primarily affects Atlantic menhaden *Brevoortia tyrannus* (Noga and Dykstra, 1986).

It is uncertain how much of these ulcerative skin disease problems are actually caused by *P. piscicida*. This is mainly because we do not yet know whether other stressors, such as hypoxia, which are also common in these estuarine ecosystems (Officer *et al.*, 1984), may also lead to skin ulceration. Nonetheless, *P. piscicida* is probably a major cause of these epidemics in some western Atlantic estuaries. There is also epidemiological evidence that chronic exposure to *P. piscicida* may lead to immunosuppression, since blue crabs (*Callinectes sapidus*) residing in areas having a high frequency of *P. piscicida* blooms have lower immune function than crabs in less impacted areas (Noga *et al.*, 1994).

Are Similar-Behaving Agents Responsible for Diseases in Other Areas?

The striking resemblance of ulcerative mycosis to certain other epidemic ulcerative diseases, such as mycotic granulomatosis (Hatai *et al.*, 1984), red spot disease (Callinan *et al.*, 1995) and epizootic ulcerative syndrome (Roberts *et al.*, 1993) suggest that a closer examination of environmental factors which may be predisposing fish to these opportunistic pathogens is essential. The apparent inability to reproduce the characteristic lesions of any of these diseases by challenging fish in a realistic manner (i.e., water-borne challenge with a biologically relevant dose of any of the suspected primary pathogens, including *Aphanomyces* fungi) strongly suggests that a major risk factor in disease development is still unknown.

Some other diseases, such as ulcerative dermal necrosis of European salmonids (Roberts, 1989) and ulcer syndrome of Atlantic cod (Larsen and Jensen, 1982) have very similar pathology to the early lesions seen with *Pfiesteria* toxicosis (i.e., spongiosis and rapid sloughing

of the epidermal epithelium). This is not to suggest that all of these diseases may be caused by *P. piscicida*, but other pathogens or environmental stressors may be acting in a similar fashion to initiate these lesions.

Other Potential Impacts of Toxic Algae

The ability of *P. piscicida* to kill or injure fish in very dilute to full-strength seawater and at a wide range of temperatures (Burkholder *et al.*, 1992), makes it a serious threat to coastal aquaculture, since it appears to be very common in certain estuarine waters and can thus be easily introduced into a culture system with contaminated water or fish (Smith *et al.*, 1988; Noga *et al.*, 1993, 1996). It is important to realize that many of the concepts used to understand and control infectious diseases are also applicable to certain noxious algae. Examples include use of isolation and quarantine, use of specific tests to detect the presence of a noxious organism, and the fact that certain toxic algae may require fish for proliferation of their pathogenic stages. This means that we need to think in epidemiological as well as ecological terms when attempting to manage these problems. Thus, our concept of "infectious agent" may need to be broadened to include not only true fish pathogens (eg., viruses, bacteria, etc.) but also toxic algae.

There is evidence for the transport and introduction of exotic toxic dinoflagellates in the ballast water of ships (Hallegraeef, 1992). The widespread movement of many aquatic animals around the world could also result in unwanted introductions of such organisms into the aquaculture environment. Thus, there needs to be plans developed for more stringent monitoring and certification of movements of aquatic animals to prevent such introductions.

There is also concern about whether *P. piscicida*'s toxins may accumulate in the edible flesh of aquatic animals exposed to blooms (McClellan-Green *et al.*, 1997) and whether other routes of exposure may be a risk to human health (Glasgow *et al.*, 1995). The most well-recognized economic impact of toxic algae is seafood contamination by their toxins. This has caused major economic losses in shellfish, including cultured species (Shumway, 1990). Other toxic algae are known to cause serious illness in persons exposed to their toxins (Pierce *et al.*, 1990). Thus, the presence of *Pfiesteria* and other toxic algae pose a serious threat to the future success of marine aquaculture and there needs to be intensified efforts to address these problems.

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