

Harmful algal blooms and aquaculture

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Harmful Algal Blooms and how they are Linked to Aquaculture Abstract

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These effects are come from the complexity of harmful algal species; the toxins they create and morphology they have adapted. Science still lacks a full understanding of factors that are involved in blooms formation.

Aquaculture and harmful algal blooms are directly related because it is one of many anthropogenic factors that unintentionally produce the conditions that promote harmful algal blooms.

The methods of production, feeds used, waste produced can lead to nutrient loading and eutrophic conditions by releasing essential nutrients into water that are necessary for algal growth. Phosphorus and nitrogen compounds are two of the main byproducts of aquaculture that are associated with bloom formation. To minimize the effects of harmful algal blooms on aquaculture you must understand the diversity and complexity of harmful algal blooms and their relationship with aquaculture. Abstract Harmful algal blooms cause a wide range of negative effects on aquaculture.

These effects are come from the complexity of harmful algal species; the toxins they create and morphology they have adapted. Science still lacks a full understanding of factors that are involved in blooms formation. Aquaculture and harmful algal blooms are directly related because it is one of many anthropogenic factors that unintentionally produce the conditions that promote harmful algal blooms. The methods of production, feeds used, waste produced can lead to nutrient loading and eutrophic conditions by releasing essential nutrients into water that are necessary for algal growth.

Phosphorus and nitrogen compounds are two of the main byproducts of aquaculture that are associated with bloom formation. To minimize the effects of harmful algal blooms on aquaculture you must understand the diversity and complexity of harmful algal blooms and their relationship with aquaculture. Andrew Blajda Introduction Over the last several decades harmful algal blooms events or HABs are believed to be increasing in frequency and geographic range. The reported increase is a major concern because of the wide scale impact they have on the environment and human activities. The effect of HABs on aquaculture can be very damaging with reduced growth, mortalities or accumulation of toxins. If aquaculture operations take place in the open bodies of water they have little or no way of avoiding incoming blooms. Harmful algal bloom events that come in contact with aquaculture operations often have negative effects that can include stunted growth, weakened immunity, mortalities, and on economic losses.

One of the bigger concerns today is the apparent increase in harmful bloom events. Researchers have linked this increase with anthropogenic activities, aquaculture being one of them. Aquaculture operations add additional nutrients to the system, this lowers nutrients that limits algal growth. A better understanding of the dynamics and characters of the bloom and make up a bloom combined with a better understanding of nutrient loading of aquaculture could potentially help reduce the negative effects harmful algal blooms have on aquaculture.

Single celled microscopic algae like phytoplankton are the most globally abundant species and one of the oceans' most important resources. These

autotrophic primary producers form the bottom of the food pyramid, acting as the primary source of food for larval finfish, crustaceans, filter feeding bivalves, and other species (Hallengraeff, 1995). In normal concentrations, these single celled algae work in balance with the ocean and its inhabitants, filling important roles in chemical and nutrient cycles. They act as primary producers, providing nutrients and food for variety of different species.

These simple microscopic species are vitally important to the success of both fisheries and aquaculture, but in some situations they can also have detrimental effects on the marine and coastal environment and numerous terrestrial and marine species. A combination of physical, chemical, biological, hydrological, and meteorological events can generate appropriate conditions that allow these simple single celled microalgae can exhibit exponential growth and reproduction. These natural events create the opportunity for algal bloom formation with potential large scale negative effects throughout the area they cover (Graham, 2007).

Algal blooms can be very diverse and differ from one another in many ways . How they form, the algal species of causation, characteristics and dynamics of a blooms, the species they affect, and impacts they cause are some of the complex factors that are found in blooms (Zingone & Enevoldsen, 2000). The specific characteristics used to define a harmful bloom vary by sources. Hans Paerl, among others, defined harmful blooms by using several characteristics. Paerl also defined harmful blooms at their most basic level by classifying them as having nuisance conditions, meaning ecological and/or economic impacts (Paerl, 1988).

As harmful algal blooms move across the ocean, the observable effects they cause go beyond the ocean and marine species it covers. These events will also have wide spread negative impacts on costal terrestrial organism and both humanhealthand activities. Algal species produce sevrsl different toxins that are detrimental effects to human health, causing various illnesses and mortalities. About 10% of foodborne disease in the United States results from algal toxins; worldwide they cause more than 60, 000 intoxications a year. Van Dolah, 2000) Economic losses due harmful algal blooms have been estimated in the tens of millions of dollars, from costs of beach clean ups, decreased tourism, and closing or stopping sales of commercial fisheries and aquaculture (Van Dolah et al. , 2001). Over the past several decades there has been an apparent increase in the frequency and geographic range of harmful algal blooms. This apparent increase has been attributed to both increased observations and focus on harmful algal blooms and increased inputs from anthropogenic sources.

Aquaculture is one of many anthropogenic activities that is believed to be hypernutrification and eutrophic conditions in surrounding bodies of water. This paper will attempt to gain a better understanding of diversity of harmful algal blooms and also the effect aquaculture has on the environment in adding in formation of harmful algal blooms. Algal Blooms Historically algal blooms are a naturally occurring phenomenon in earth's oceans and have been observed throughout recorded history (Hallegraeff, 1993).

These events are often beneficial to bivalves by supplying an abundant food supply to these filters feeding that relay on microalgae for their source of nutrients. Algal blooms can quickly turn into detrimental to the environment

and its inhabitants are various ways (Leverone, 2007). Sources from human history including the bible may contain the first documented cases of algal blooms. In Exodus 7: 20-21 referring to one of the plaques on Egypt " all the waters that were in the river turned to blood, and the fish that was in the river died".

Some historians and scientist now believe this biblical reference from 1,000BC could be the first written record of an algal bloom. (Hallegraeff, 1993) Other historical sources may have unknowing recorded written evidence on algal blooms, in China around 200AD general Zhu Ge-Ling documented sicknesses and losses of military personnel after drinking from a river that was stained green. (Chorus & Bartram, 1999) Examination of fossil algal specimens and historical reference compounding evidence that these event are not a new phenomenon and have been occurring in earth's oceans for thousands if not millions of years.

Recent finding from numerous long term studies conducted around the world has brought a strong belief in the scientific community that algal blooms have been increasing in their frequency and geographic distribution. Even though most scientiest support the idea of a global increase of blooms and twith strong evidence supporting this theroy there is still a major dissagreement about what is causing the increase (Pelley, 1998). The apparent increase of algal blooms, along with the global impacts on aquatic organisms, the environment, human health, and activities has increased interest and research being done on these events (Li et al. 2002; Van Dolah et al. , 2001). The exact characteristics and descriptions that define an algal bloom are fairly broad and very from source to source. I was unable to find a

universal definition of algal blooms. The description and definition I came across were similar but differed in many aspects; this included sizes, formation factors, impacts, and algal species. Overall algal blooms are generally defined significant increase in biomass due to a rapid reproduction of a single microalgal species.

The problem with this source is there can also be macroalgal blooms. Others described them as forming high density populations, with some species creating visible discoloration of the water. (Carstensen, Henriksen, & Heiskanen, 2007; Diersing, 2009) Others define blooms by impacts they cause; displacing indigenes species, destroy habitat, oxygen depletion, and alter biochemical cycles. (Hoagland et al. , 2002) A more generalized definition was given by Hallegraeff, adding that a bloom must have at least million cells per liter (Hallegraeff, 1993).

The defining characteristic that differentiates a bloom from a harmful algal bloom is when they takes on a destructive roll and causes environment impacts. The term harmful is defined more specifically as causing negative impacts on the environment and adverse effects on both aquatic and terrestrial organisms. This is due to factors such as toxins they produce, specie specific cell physical structure causing damage to aquatic organisms or by accumulation of biomass affect naturally occurring organisms causing alterations food web dynamics and biochemical cycles (Anderson et al. 2002). Depending on the species, some algae produce toxins that can affect crustaceans, fish, shellfish, birds and mammals including humans; nontoxic species can still causes damage by blocking light from penetrating the water column, clogging or damaging gills, and creating anoxic conditions from

accelerated decomposition as they die off (Silver et al. , 2006; Sellner et al. , 2003) Harmful alga can also have impacts on shoreline coastal habitats, toxins can be transported onto the shore by sea spray (Hoagland et al. , 2002).

There are over 5, 000 known photoplanktonic algal species that inhabit the marine waters only a small portion, about 300 species are known to have blooming capabilities and even fewer, about 40-80 species or 2-3% of all photoplanktonic algal species are known to have toxic chemicals producing capabilities; this includes members that form red tides (Hallegraeff, 1993; Smayda, 1997). Nontoxic red tides are not uncommon, today people often incorrectly or mistakenly refer to toxic algal blooms as red tides even when brown, green or colorless (Anderson, 1994).

Toxic and other harmful algal species are ubiquitous throughout the marine and freshwater environment; the majority of the time they present at low population densities that cause few, if any and only minor impacts on the environment and its local inhabitants (Van Dolah, 2000). There are a variety of different phycotoxins algal species are able to synthesize; individual species will only produce one type of toxin. The evolutionary advantages of these toxins are not fully understood; they are believed to play a role in bloom formation and predator protecting (Nehring, 1993).

The different phycotoxins vary from one another in terms of the impacts and degree of damage they have on marine and terrestrial organisms, depending on the toxicity, the concentration, and the organisms. Toxicity vary among algal species Dinophysis is one example, they have the ability to produce toxins that have negative effects at densities as low as 100 cells per L-1

(Sellner et al. , 2003). The most toxic algal species are mainly found in dinoflagellates (Table 1) with some having toxicity greater than venomous snakes. Table 1.

Toxicity of several phycotoxins created different organisms including algae. (Van Dolah, 2000) The taxonomic algal groups' dinoflagellates, raphidophytes, cyanobacteria, and some diatoms are known to have the capabilities of phycotoxins production; these species are often the culprit behind harmful algal blooms. Phycotoxins are toxic chemicals created biologically by photosynthetic organisms. Dinoflagellates are one of the predominate species that forms red tides; members of this group also produce toxin that lead to foodborne illness and human mortalities (Li et al. , 2002; Hallegraeff et al. 1995). Human induced illnesses are not an uncommon result from consumption of seafood. Many algal toxins are potentially dangerous and even deadly to humans. Toxins accumulate in tissues of organisms like shellfish, finfish, and crustaceans that come in contact with a toxic bloom. These species are usually far less affected by algal toxins having adaptive mechanisms that lower the effects on the organisms associated with toxic blooms. However toxins still accumulate within the tissues and detoxification can take weeks before they reach levels safe for human consumption.

Algal toxins cause for concerns for humans not only because they maintain their toxicity long after the bloom but more importantly because they can withstanding heat from cooking. Algal toxin foodborne diseases are caused by various species or toxins and come from different vectors. Bivalve vectors can induce human illness that include (Table 2) paralytic shellfish poisoning

(PSP), neurotoxic shellfish poisoning (NSP), amnesic shellfish poisoning (ASP), diarrhetic shellfish poisoning (DSP); other vectors can lead to various other diseases as well (Van Dolah, 2000).

The popular term of red tide given to harmful algal bloom comes from compact, high densities of algal cells that containing red photosynthetic pigments, causing the water to appear red (Carstensen et al. , 2007). These toxic species can normally be found in low concentrations have no impacts on organisms and environment. The adverse effects on organism often deepened on cell concentration; in blooms toxic algae aggregate and are more dangerous (Van Dolah, 2000).

Some toxic algal species have developed unique life cycles and morphological characteristics that allow them to occupy a specific niche that will be further examined. Table 2. Foodborne and environmental disease caused by harmful algal species, the toxin produced and the primary vector they inhabit. (Van Dolah, 2000) Harmful algal species have many adverse impacts on bivalves' this includes a wide range of sub-lethal and lethal effects; some algal species are more detrimental than others (Leverone, 2007). It is believed that increase frequency of blooms is partially due to the introduction of non-indigenous algal species.

Non-indigenous species potentially will create a specific niche, and/or out compete native species. Indigenous naturally occurring harmful algal species are far less direct effects on bivalves; this is because they have been able to naturally adapt to their presence over time. Native algal species in most case do not have as bad direct, detrimental impacts on shellfish and are usually not associated with large scale bivalve die off. The exception to this

is in cases of intense blooms (Matsuyama & Shumway, 2009; Nehring, 1993; Zingone & Enevoldsen, 2000).

It's still hard to truly say many large scale die-offs and increase sub-lethal impacts are directly due to non-indigenous algal species because identification is sometimes difficult, longer term data individual algal species geographic ranges are limited combined, and the theory anthropogenic factors are causing an overall increase in blooms. In many circumstance of HAB mortalities it's difficult to differentiate whether they resulted from the algal specie or unfavorable water quality that coincide with blooms (Anderson et al. , 2002; Leverone, 2007).

Complex morphology are found in many harmful algal species that helps protect them from predation and the environment and help obtain nutrients. Diatom algae are members of the Bacillariophyceae class; they have been around for over 180 million years helping to create earth's atmosphere and also play a major role in nutrient and chemical cycles. Over their evolutionary history diatoms have developed a variety of different exterior cellular morphology for protection from the environment and predation. They have a range of cell shapes and sizes and also form unique frustule cell walls made from silica.

The frustule cell wall is made up of two over lapping overlapping silica bands forming a protective shell. The 100, 000 diatom species have developed “seeming infinite variations” of cell wall micropatterns and structures; including ridges, spines and plates (Kroger & Poulsen, 2008) These cellular morphological characteristics help protect them under adverse environmental conditions and restrict or prevent predation. Some species of

diatoms have developed such strong cell walls with structural properties that enable them to survive ingestion and escape after passing through the digestive system. (Merkel, et al. 2003) The benefits of these structures do have negative effects and come at the expense of motile abilities, limits growth, and makes the cell very dense; motile restorations and high cell densities make diatoms much more likely to sink out of the high nutrient water column. Bloom Formation The intricacy of bloom formation is due to both the abiotic(environmental and anthropogenic factors) and biotic factors; these being the algae themselves. Adaptations of life cycle, morphology, and environmental conditions enable rapid reproduction of certain algal species that have developed specific niches (Sellner et al. 2003; Zingone & Enevoldsen, 2000). Algal blooms formation driven by the complex relation between the environmental factors and algal species; although we understand the basics of formation there are still many unknowns. There are seemingly endless amounts of variables and factors that play a role in creating of a bloom. The main driving factors of when and where a bloom forms are a combination of environmental/anthropogenic factors (nutrient cycles and inputs) and algal morphology (Pinckney et al. , 1997; Sellner et al. , 2003).

As simple as it sounds, there are countless variables including natural condition, anthropogenic effects, algal physiological and morphological characteristics that lead to the unpredictability and overall misunderstanding we still have on blooms. (Sellner et al. , 2003; Anderson, 1994) The belief that algal blooms are increasing in frequency and geographic range is a popular belief that is backed by numerous studies. The cause of this

apparent increase has been attributed to the expanding human population (anthropogenic effects).

Some still argue that the increase in blooms is due to the increase in observations from studies worldwide, a better understanding of blooms and better record keeping; but with overwhelming evidence supporting the lateral it's hard to believe the human race is not playing a major roll. (Sellner et al. , 2003) Looking at the number of literary reference to harmful algal bloom over 70 years (figure 1) shows a dramatic increase algal blooms from the 1920's through late 1990's (Hallegraeff, 1993). This also give arguments that increase research and technology contribute to the increase over time.

Figure 1. Literary references of harmful algal blooms from Aquatic Sciences and Fisheries Abstract (AFSA) publications over about 70 years. The increase can be attributed to a combination of anthropogenic factors or increased observations and present arguments for both sides. (Hallegraeff, 1993) Today we have an understanding of the natural environmental processes and factors that lead to bloom formation; but the effects humans apply to the environment alter the natural cycles making it more difficult to predict blooms (Paerl, 1988).

Blooms occur under irregular conditions that promote growth and reproduction allowing some species to flourish. The conditions found in blooms broad and often species' specific adding to the complexity and unpredictability of blooms. In general the conditions associated with blooms are abundance (eutrophic), or an imbalance of nutrients, along with favorable water conditions (temperature, DO, salinity, etc.). Natural processes like atmospheric deposition, water column turnover, upwelling,

oceanic currents, storms, and anomalous weather events (El Nino) work together and fluctuate over time effecting mixing rates, water quality.

Nutrients pools build up over time from organic decomposition in benthic sediment. Mixing of the sediment perelapses the nutrient pools and bring about eutrophic conditions or alter the water chemistry that enable specific species of algae to flourish (Sellner et al. , 2003; Van Dolah, 2000; Paerl, 1988). Natural mixing rates occur during regularly during temporal or seasonal with environmental fluxes or randomly from disturbances (natural anthropogenic). Sediment mixing are very important environment processes, releasing nutrients back into the water column allowing for increased primary producer growth.

Seasonal and temporal sediment mixing produce lead to the specific conditions that form blooms. Eutrophication has been defined as “ an increase in supply of organic matter to the ecosystem; in terms of algal bloom this refers to an increase in nutrients that allows an increase of primary production” (Bonsdorff et al. , 1997). Three key nutrients, nitrates ammonia and phosphates are associated with eutrophication and considered the driving forces behind bloom (Sheng, Jinghong, Shiqiang, Jixi, Dingyong, & Ke, 2006). The levels found in marine waters are driven naturally based on natural events discussed above.

Studies have found a correlation between anthropogenic actives leading to nitrogen and phosphorus nutrient loading and the apparent increase in frequency of algal blooms along with alteration of natural nitrogen/phosphorus ratio (Bonsdorff et al. , 1997; Paerl, 2009). There are various anthropogenic activities that have led to the both local and global

increase of nutrients in fresh and marine waters. Aquaculture is just one of many of these activities. Many studies have shown that aquaculture operations have byproducts that can cause eutrophic conditions.

Nutrient loading from aquaculture only has local effects and the amount of effects it causes is size dependent (Anderson et al. , 2002). Aquaculture and Nutrient Loading It is important to understand the relationship between aquaculture and harmful algal blooms. Additional nutrients from the feed used, effluent discharge, and waste products are some of the source that lead to nutrient loading (Tacon & Forster, 2003). The amount of additional nutrients added to a system increases based on how intensive the operation is.

HABs have wide spread negative impacts on aquaculture, the hope of significantly minimizing these impacts are still years away. To minimize the effects on aquaculture you must understand characteristics and dynamics of blooms, this includes the diversity of species involved and the factors associated with bloom formation. The apparent increase frequency and geographic range of harmful algal blooms is very important to aquaculture because aquaculture plays a role in helping create the conditions necessary for bloom formation.

Aquaculture operations provided year round nutrient inputs in a local aspect, this eliminates nutrient limitations in those areas (Bonsdorff et al. , 1997). This section will discuss and review the relationship aquaculture has with nutrient loading and eutrophication of the surrounding water. Nitrogen and phosphors are to key elements that take on various forms necessary for

bloom formation. Both nitrogen and phosphors in the forms of nitrates, ammonia, phosphates and other compounds are byproducts of aquaculture.

Algal growth is limited by nutrient availability, mainly based on availability of nitrogen and phosphors in the environment. Nitrogen in the forms of nitrates and ammonia are water soluble and enter the system from either dissolved feeds, effluent discharge, or from waste produced by fish. Phosphates often accumulate mainly in the sediment and during mixing events are released into the water in high quantities (Karakassis, Pitta, & Krom, 2005). Nutrient loading from aquaculture that leads to eutrophic conditions come from several sources. The amount and source of the nutrients depends on the operation.

Location of farm (open ocean, ponds, raceways etc.), what is being cultured (shrimp, finfish, bivalves), what are the inputs (feeds, fertilizer, etc.) and how intensive the operation is. The source of local nutrient loading from aquaculture can be traced back to where the operation is taking place. Open ocean farming of finfish for instance causes eutrophic conditions right around the cages. On the other hand inland facilities such as pond systems and other flow through systems release effluent discharge causing nutrient in the and around the bodies of water they run into.

The species being cultured also plays a major role. Bivalves for instance play a role in limiting algal growth by filter feeding, while finfish inputs and excreting essential nutrients in their waste is a major source of nutrients (Soto & Mena, 1991). How intensive an operation is and the actual inputs into the system are directly related. The more intensive an operation the more inputs and the more inputs the greater chance of hypernutrification

and eutrophic conditions. Different operations require different inputs and these inputs have different nutrient ratios. Culture of some juvenile finfish require fertilization to promote phytoplankton growth for feed this puts the essential nutrients for algal growth directly into the system. The feeds used in aquaculture vary on the nutrients they are made up of, how stable they are and whether they float or sink. These factors are all in play in nutrient loading that come directly from aquaculture (Islam, 2005). The effects of aquaculture feeds on nutrient loading depend on several factors. There are three main factors these include; 1) the amount of wasted feed.

This is due to poor farming and management practice and floating Vs. sinking feeds. Poor management practices means over or an improper feeding technique that puts more feed in the water. Floating and sinking feed choices is also important. Sinking feeds may not be eaten by finfish if they go through the bottom of a net or cage, or if they sit on the bottom. On the other hand floating feeds may be less stable or uneaten if they are transported out of a system or to a place where they are unable to be eaten.

2) The actual quality of the feed.

This poor stability and high solubility of feed pellets in water mean that once they are in the water they will be broken down and release more and nutrients and in less time. The final factor is deals is loosely related to the previous two. 3) Once the feed is ingested factors such as limitations of absorption and retention of the nutrients from the feed. This factor deals mainly with poor digestibility or metabolism of the species being culture to the feed they are given. The nutrients in the feeds many not be utilized to

their full potential once ingested fish will excrete the excess nutrients (Soto & Mena, 1991).

Feed and nutrient inputs play a major role in nutrient loading and creating the conditions that promote algal growth either directly in the form of uneaten feeds or nutrients leaching or dissolving from the feeds, or indirectly from the digestion, metabolism and waste products from the species being cultured (Tacon & Forster, 2003). The importance of feeds in nutrient loading must not be overlooked one study estimated that 70% of phosphorus and 30-50% of nitrogen in feeds is not utilized by fish and is released into the environment (Soto & Mena, 1991).

This only shows two of the most essential nutrients associated with bloom formation and not the various other nutrients that are also released and are important for algal growth. This also shows the significance of feeds based on the large amount of nutrients that are not utilized and instead entering the environment, promoting algal growth. Over all aquaculture farm operations lead to excessive amounts of inorganic and organic fertilizer, feeds, and wastes that are put into local water bodies with high concentrations of nutrient, that lead to nutrient loading and eutrophic conditions.

Discussion and Conclusions Aquaculture over the last several decades has grown globally in both its production and popularity. In the future aquaculture will continue to grow in its importance to the human population as alternative food source to agriculture and wild fisheries, as well as helping with the depleted ocean stocks. As of now it appears that we will be seeing an increase in aquaculture around the world in the years to come. Although

there are many benefits to aquaculture and the potential of increased production may have we must measure the benefits against the environment impacts they cause.

Nutrient loading is just one of the environmental impacts associated with aquaculture and the effects of nutrient loading go beyond promotion of algal blooms. The global increase in aquaculture coincides with the apparent increase in harmful algal. Although there are many other anthropogenic factors that are at play in global nutrient loading aquaculture is a major local point-source form. We must understand the specific conditions that are associated blooms and the role aquaculture plays along with how complex and diverse blooms can if we hope to develop mechanisms that can significantly reduce the impacts on aquaculture.

I choose the topic of harmful algal blooms and aquaculture effects of nutrient loading because it fits in perfect with our class: aquaculture and the environment. The purpose of this paper was to gain a general understanding of harmful algal blooms, and also to review the factors of aquaculture that lead to nutrient loading, eutrophic conditions, and the aid in bloom formation. This topic caught my attention because of similar topics I've cover and work I've done this semester in this class and others classes.

Harmful algal blooms in general are very interesting because of the diversity of blooms, the range of effects they have, how unique the species involved are, and because of the complexity and over all lack of understanding have in factors of bloom formation. The purpose of this class included reviewing the impact of aquaculture on the environment and methods of reducing or

eliminating those impacts. This paper focuses on harmful algal blooms and how aquaculture creates conditions that promoted bloom formation.

I focused a great deal of this paper on harmful algal blooms because if you hope to minimize the impacts they cause you must appreciate and understand their complexity and also understand the relation they have with aquaculture. The purpose of this paper was not to examine direct ways in which to minimize nutrient inputs of harmful algal blooms but the information given on harmful algal blooms and the role aquaculture plays in promoting bloom formation is useful to future studies and reviews focusing on ways to minimize the impacts of HABs on aquaculture and help reduce the factors of aquaculture that promote harmful bloom formation.

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