Water Quality and Harmful Algae in Southeastern Coastal Stormwater Ponds

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Introduction

Several long-term monitoring studies describing the water quality and biological condition of Southeastern estuaries (National Estuarine Eutrophication Assessment Project, South Carolina Estuarine and Coastal Assessment Program (SCECAP), Environmental Monitoring and Assessment Program (EMAP), South Carolina Harmful Algal Bloom Program (SCHAB), South Carolina Tidal Creek Project, and others) have been developed. Many of the same water quality issues determined for open estuaries are also found in coastal stormwater ponds, and there are important interactions between the man-made ponds and the natural systems. Researchers have highlighted problems such as nutrient eutrophication, bacterial and chemical contamination, hypoxia, and harmful algal blooms (HABs). This technical memorandum summarizes the state-of-the-knowledge of water quality indicators (dissolved oxygen, nutrients, and chlorophyll *a*), and harmful algae in Southeastern coastal stormwater ponds.

Water Quality

Poor water circulation and high pollutant loading from urban areas contribute to a number of water quality problems in stormwater ponds (Novotny 1995). Eutrophication can be induced by runoff after fertilizer applications, fecal material input, and additional urban runoff from domestic wastewater and impervious surfaces (Bricker et al. 1999, WHO 1999). High nutrient levels can lead to excessive algal growth (e.g. Glibert et al. 2001) and the potential development of harmful algal blooms. Stormwater ponds in the Southeastern coastal zone are

often characterized as having stratified water columns, high concentrations of nutrients, and warm water temperatures.

Serrano and DeLorenzo (2007) describe some of the water quality conditions expected in coastal stormwater ponds. Measurements were collected from 2004-2005 for an 11-acre freshwater stormwater pond (Lake Edmonds (LE)) and the adjacent tidal creek (Kushiwah Creek (KC)). There were high dissolved oxygen (DO) concentrations associated with algal bloom development, but average summer DO concentrations were below the guideline of 4 mg/L where water quality is considered poor and potentially stressful for organisms (SCDHEC 2001). Tidal creeks are normally stressful sites for DO; for example, monitoring data showed that 46% of SC tidal creek habitat had a daily average bottom DO <4 mg/L during the summer (Van Dolah et al. 2002). Algal blooms add to the variability in DO, inducing very high DO during the day, then very low DO at night, and when the bloom dies.

The average monthly total nitrogen concentrations in Lake Edmonds for July and November of 2004, and February and March of 2005 exceeded the EPA criteria of 0.37 (0.32-0.41) established for reference lakes and reservoirs and would be considered eutrophic (USEPA, 2001). Similarly, average monthly nitrogen levels in Kushiwah Creek exceeded the estuarine eutrophication guideline of 1mg/L (Bricker et al. 1999) in June, August, and December of 2004, and in March and June of 2005. Both the lake and creek would be considered highly eutrophic in terms of phosphorus throughout the year. All pond and tidal creek samples had higher orthophosphate concentrations than the total phosphorus guideline for lakes and reservoirs (0.036 mg/L (0.024-0.048 mg/L)) (USEPA 2001) and estuarine waters (0.1 mg/L) (Bricker et al. 1999). Maximum levels of chlorophyll reached 280 µg/L (June 2004) for LE and 150 µg/L for KC (July 2004). All of the samples collected from LE had higher chlorophyll levels than the USEPA

eutrophication standard of 4.1 µg/L established for lakes and reservoirs (USEPA 2001). For

KC, all of the samples except December through May 2005 exceeded the chlorophyll hyper-

eutrophic guideline of 60 µg/L, established for estuarine waters (Bricker et al. 1999). The high

chlorophyll concentrations measured in both the stormwater pond and the tidal creek

corresponded with dense algal blooms in the pond. There was a significant positive relationship

(Kendall's multiple correlation analysis) between chlorophyll levels and nitrate/nitrite

concentrations in LE (R = 0.34, p= 0.026), suggesting a relationship between nutrient levels and

algal bloom development.

   In conjunction with and in response to the 2006 Stormwater Pond Initiative, South

Carolina Department of Health and Environmental Control-Office of Coastal Resource

Management (SCDHEC-OCRM) conducted a baseline study of the water quality conditions in

112 coastal stormwater ponds. The study found that although nutrients tended to be low and DO

tended to be high (DO > 4 mg L^{-1} in 79% of the ponds), chlorophyll a concentrations were high

(≥ 40 µg L^{-1} in approximately 32% of the ponds) (SCDHEC 2007). Analysis of the 25 samples

with chlorophyll concentrations > 60 µg L^{-1} found that 80% contained algal blooms, including

HABs (SCDHEC 2007).

   In North Carolina, Mallin et al. (2000, 2004) also reported elevated levels of nitrogen to

be associated with increased phytoplankton productivity, hypoxic and anoxic conditions, fish

kills and the loss of submerged aquatic vegetation. In a 2002 to 2005 survey of six Kiawah

Island, SC ponds, Brock (2006) found a mean DIN:DIP ratio of 0.23, indicating that maintenance

of high phytoplankton biomass would presumably be limited by nitrogen rather than phosphorus

supply, and suggesting that management strategies targeting nitrogen reduction would be more

effective in mitigating pond eutrophication than those targeting phosphorus. Brock (2006) also

reported that nutrients were seasonally variable, and highly available to phytoplankton communities when in the inorganic form (i.e., nitrates, nitrites and ammonium). Mean chlorophyll *a* values were classified as highly-eutrophic to hyper-eutrophic (Bricker et al. 1999) for all ponds, and in all seasons. Mallin et al. (2002) surveyed several North Carolina wet detention ponds and found highly variable nutrient removal efficiency. Some ponds were very effective in removing nutrients, while others had greater nutrient concentrations in the pond outflow compared with the inputs. This indicates potential for inefficient coastal stormwater ponds to serve as sources of nutrient loading contamination for estuaries. Paerl (1997) suggested that the increase in anthropogenic nutrient inputs in recent decades have transformed previously oligotrophic coastal waters to eutrophic status. These nutrient impacted coastal waters have been experiencing what Smayda (1990) describes as an epidemic increase in HABs.

Harmful Algal Blooms

The prevalence of HABs in SC coastal ponds is an indication of their eutrophic state. The association between coastal eutrophication and HAB prevalence has been an issue of growing concern over the last two decades (Smayda 1989, 1990, Hallegraeff 1993, Paerl 1997, Burkholder 2001a, GEOHAB 2001). In fact, the prevalence of HABs is thought to have increased globally over the last 2–3 decades, and has been attributed to an increase in anthropogenic nutrient loading (Anderson 1989, Smayda 1990, Hallegraeff 1993, Paerl 1997). Lewitus et al. (2003) described stormwater ponds as "incubators" for harmful algal blooms (HABs). "Harmful algal blooms pose a serious threat to human health and are economically challenging to our coastal communities," said retired Navy Vice Admiral Conrad C. Lautenbacher, Jr., Ph.D., former Undersecretary of Commerce for Oceans and Atmosphere and NOAA administrator.

In response to stormwater pond HABs, the SC Task Group on Harmful Algae (www.scseagrant.org/oldsite/schab.htm) was formed in 1997, to monitor HAB events and inform the public of HAB risks. The South Carolina Harmful Algal Bloom Program (SCHABP) was created in October 2000 as a statewide, coordinated research effort to document the statewide distribution of HABs in SC. The program consists of seasonal monitoring for HABs and response to acute events. The SCHABP has documented HABs of 26 species, determined the common presence of HABs in coastal stormwater ponds, and established the association of HABs with SC fish kills either indirectly (through oxygen depletion) or directly (through toxin production). The SCHABP also promotes outreach to educate SC citizens, managers, and public officials about HABs.

The volunteer Phytoplankton Monitoring Network (PMN) is a NOAA-sponsored community outreach program developed to increase awareness of harmful algae to constituent groups and directly involve volunteers in coastal stewardship by participation in phytoplankton sampling and identification. Currently the program has 103 sites from North Carolina to Texas, with additional sites in Massachusetts, Hawaii and the US Virgin Islands. The majority of the volunteer groups include teachers and students, however universities, aquariums, and environmental and citizen groups also participate. During 2006-2007, approximately 2000 participants were actively involved in PMN programs and monitoring activities. Volunteers are instructed on algae identification and sample on a weekly or biweekly basis, reporting their data via a secure web portal to researchers at the Marine Biotoxins Program. Data from volunteer groups enable researchers to identify problem areas to isolate for further study. Since the inception of the program in 2001, over 70 blooms have been observed by volunteer groups (http://www.chbr.noaa.gov/pmn/).

Twenty-five harmful algal bloom species have been identified in South Carolina waters (Wilde et al. 2005). Most blooms are attributed to cyanobacteria, raphidophyte, and dinoflagellate species. Many of these blooms have been associated with measured toxins, fish kills, and shellfish stress indicators (Wilde et al. 2005).

Cyanobacteria

Algal toxin production depends on several factors such as the biology of the algae (toxic vs. non-toxic strains), environmental factors (Aboal and Puig 2005), and the physical condition of the cell (Orr and Jones 1998, Vézie et al. 2002). In freshwater and brackish systems, toxins are most commonly produced by cyanobacterial (blue-green algae) species (Watanabe et al. 1995, Onodera et al.1997, Vieira et al. 2005). The presence of cyanotoxins in the water may represent a risk to residents who use the pond for recreational activities such as boating and fishing (WHO 1999, Van Dolah et al. 2001, Balmer-Hanchey et al. 2003). In addition, health risks to domestic and wild animals that drink or swim in the water from the pond are possible. Dense cyanobacterial blooms can also be associated with unpleasant odors and undesirable views that may lead to decreased property values.

The hepatotoxin, microcystin, is produced by several cyanobacterial species of the genera *Microcystis*, *Anabaena*, *Nostoc*, and *Oscillatoria* and represents a concern to human, wildlife, and pet health (WHO 1999, Freitas de Magalhaes et al. 2001). Exposure to microcystin can be through oral and dermal exposure to contaminated water (WHO 1999, Van Dolah et al. 2001, Balmer-Hanchey et al. 2003). Many of these HABs species have been documented in South Carolina coastal stormwater ponds (Lewitus et al. 2003, Brock 2006, Serrano and DeLorenzo 2007).

Dense cyanobacterial blooms (concentrations greater than 1000 colonies/mL) occurred throughout a two-year sampling period of a coastal, residential stormwater pond, Lake Edmonds (LE) and the adjacent tidal creek, Kushiwah Creek (KC) (Serrano and DeLorenzo 2007). These blooms were produced by species of the genera *Anabaena* (*A. circinalis*, *A. spiroides*, and *A. spherical*) and *Microcystis* (*M. aeruginosa*, *M. incerta*, and *M. flos-aquae*). Downing et al. (2001) showed that phosphorus concentrations greater than 10 μg/L can induce a dominance of cyanobacterial species over other phytoplankton genera, which is consistent with the observed blooms of *Anabaena* and *Microcystis* in Lake Edmonds throughout the sampling period 2004-2005, when average monthly phosphorus levels ranged from 29 to 1580 μg/L.

The cyanobacterial species documented in LE are known to produce the algal toxin microcystin (Freitas de Magalhaes et al. 2001). Microcystin was detected in several samples from all sites within LE and KC, some of which had concentrations exceeding the World Health Organization drinking water guideline of 1μg/L microcystin-LR (WHO 1999). There is not currently a microcystin guideline for surface waters. Microcystin concentrations exceeded the WHO standard in LE during September 2004, November 2004, and July 2005, and most of these detections were associated with algal blooms. Detection of microcystin toxin concentrations greater than 1μg/L, although infrequent during the sampling period may be significant as this toxin is able to accumulate in the liver of aquatic and terrestrial organisms (WHO 1999, Freitas de Magalhaes et al. 2001). Previous sampling in LE by the SCDNR-AEL found microcystin concentrations in July 2003 as high as 1926 μg/L (SCHABP final report 2001-2005).

Anabaena sp. and *Microcystis* sp. were also detected in the adjacent estuary, KC, in 39% of the samples collected during 2004 and 2005, of which 78% of the detections coincided with algal blooms in LE. Microcystin was detected in samples from the creek, coinciding with

presence of the toxin in the pond. The microcystin concentration in KC exceeded the WHO standard in July 2005. The chemical stability of microcystin will allow it to persist in the environment for several days or weeks after bloom decay (Lahti et al. 1997) at salinities up to 24 ppt (Mazur and Plinski 2001). Brock (2006) documented a persistent *Microcystis* bloom (lasting four-months, from September through November 2004) in a Kiawah Island brackish pond, with measured toxin levels always > 1 µg/L, and as high as 10,000 µg/L.

Based on long-term monitoring of coastal stormwater ponds by the SCDNR-AEL, cyanobacteria were commonly the dominant phytoplankton species in low salinity waters. For example, a compilation of samples from 2001-2005 blooms by several cyanobacterial species spanned all salinities, but 71% of these occurred at salinity ≤ 10 ppt. Among the three most prevalent species, *Microcystis* bloomed most often at this low salinity range (86% of these blooms were at ≤ 10 ppt) but 63% of these were between 5.1 and 10 ppt. *Anabaena* also bloomed mostly (72%) at salinities ≤ 10 ppt, while *Oscillatoria* blooms were more euryhaline, with 50% > 10 ppt and 29% > 20 ppt. Many of these blooms were associated with measured toxins, fish kills, or shellfish health effects (Kempton et al. 2002a, Lewitus and Holland 2003, Lewitus et al. 2003, Keppler et al. 2005, 2006).

An increasing diversity of cyanobacteria species are being linked with fish disease and fish kill events around the world (Glibert et al. 2005). Researchers have documented effects of cyanobacterial toxins on fish behavior, as well as liver damage (Christoffersen 1996). Jacquet et al. (2004) demonstrated reduced survival rates of *Medaka* embryos injected with microcystin, and abnormalities such as liver hypertrophy and hepatic hemorrhage were observed in post-hatching juveniles. Anatoxin poisoning (neurotoxins produced by species of *Anabaena* and *Oscillatoria*) has been linked to deaths of dogs, sheep, cattle, pigs and geese (Carmichael 2001).

There are also examples of cyanotoxin-induced human health effects. Microcystin-contaminated water resulted in the death of approximately 70 dialysis patients in Brazil (Carmichael et al. 2001). Carmichael (2001) cites a *Cylindrospermopsis raciborskii* algal bloom event that occurred in Solomon Dam, Palm Island, North Queensland, Australia in 1979 that led to severe hepatoenteritis in 138 people. Cyanotoxins have been implicated in human illness (*i.e.*, acute non-lethal or chronic toxicity) from municipal water supplies, especially after the algal bloom has been treated by copper sulfate to lyse the cells and release more of the toxins into the distribution system. In these and other cases involving accidental ingestion, the symptoms reported include abdominal pain, nausea, vomiting, diarrhea, sore throat, dry cough, headache, blistering of the mouth, atypical pneumonia and elevated liver enzymes in the serum (especially gammaglutamyl transferase) (Chorus and Bartram 1999). Cyanobacterial exposure may also lead to tumor formation, since microcystins and nodularins have been shown to promote tumors through their inhibition of protein phosphatases (Carmichael 2001).

Dinoflagellates

Pfiesteria spp., are toxic dinoflagellates that have been linked to numerous fish kills in coastal waters (e.g., Neuse River, NC and Chesapeake Bay, MD) (Burkholder & Glasgow 1997, Glasgow et al. 2001, Burkholder 2001b). These species have also been identified in coastal stormwater ponds. In March 2001, the SCHABP analyzed water samples collected by the SC Department of Health and Environmental Control (SCDHEC) from a fish kill in a Hilton Head Island subdivision brackish pond. Microscopic analyses indicated high numbers of algae resembling *Pfiesteria* spp. Subsequent DNA-based, polymerase chain reaction (PCR) assays and fish mortality bioassays confirmed the presence of *Pfiesteria shumwayae* and *P. piscicida*.

These findings provided evidence that these species may have been a causative factor in this fish kill (Lewitus & Holland 2003).

In SCAEL monitoring samples *Pfiesteria* spp. were among the most prevalent bloom forming dinoflagellates in mid- to high-salinity stormwater ponds, but rarely reached high abundances. Monitoring efforts for *Pfiesteria* spp. in brackish detention ponds focused on 14 Kiawah Island ponds. Two ponds, "K2" and "K5", had a significantly higher prevalence of *Pfiesteria*-like organisms (PLOs). Based on light microscopy, PLOs were observed in 67% of the samples collected in "K2" and 80% in "K5". Using real-time PCR (Bowers et al. 2000), *Pfiesteria piscicida* and *P. shumwayae* were confirmed in 47% and 82% of these samples, respectively. In a survey of 60 Kiawah Island pond sediments using real-time PCR assays, *P. piscicida* was positive in 58% of the ponds surveyed, and *P. shumwayae* was positive in only 5% of the ponds. In surveys of tidal creeks that exchange water with these same ponds, PCR assays for *P. piscicida* were positive in approximately 50% of the sediment samples collected, extending up to 1.5 km from the ponds. The possibility that estuarine sediments contain *Pfiesteria* cysts has implications for the effects of dredging on increasing the distribution of these species.

In addition to causing lesions and death in fish species, there are reports of human health effects from *Pfiesteria* exposure, particularly symptoms of neuropsychological disturbance, termed Possible Estuarine Associated Syndrome (Friedman & Levin 2005). Several reports associate possible occupational (people working on the water, or in laboratories with *Pfiesteria*) exposure through dermal and/or inhalation of aerosolized toxin with neurobehavioral effects (as reviewed in Friedman & Levin 2005). Symptoms included sensory disturbance, emotional and

cognitive disfunction, stomach and respiratory irritation, and memory loss. These reports led to restricted use of Maryland waters, at a substantial economic loss (Friedman & Levin 2005).

In 2002, a brackish detention pond fish kill located in Mount Pleasant, SC, was linked to a *Karlodinium veneficum* (formerly *K. micrum*) bloom, due either to the toxicity of the dinoflagellates, or the persistence of the bloom and subsequent low DO conditions (Kempton et al. 2002a). A combination of morphological, biochemical, and molecular diagnostics was used to assess species identity of the bloom dinoflagellate, and measure toxicity of filtered water. Results from high performance liquid chromatographic (HPLC) pigment profiles, *K. micrum*-specific polymerase chain reaction (PCR) assays, and gene sequence alignments confirmed that the dinoflagellate as *K. micrum* (Kempton et al. 2002b). Results from fish necropsies also attributed fish death to an acute response. Finally, hemolytic activity and ichthyotoxicity assays measured from water sample filtrates were consistent with toxin produced by *K. micrum*. The results provide compelling evidence for toxic *K. micrum* as a causative factor in a SC brackish retention pond fish kill.

Kryptoperidinium foliaceum and another dinoflagellate with similar morphological characteristics, *Scrippsiella* sp., are known as the South Carolina "red tide" species (Lewitus et al. 2001). They are among the most prevalent HABs in SC tidal creeks (Kempton et al. 2002b, 2004, Wolny et al. 2004), with *Scrippsiella* more commonly found in tidal creeks south of Bulls Bay. Through the routine monitoring efforts of the SCHABP, *K. foliaceum* and *Scrippsiella* sp. have been identified in 570 and 351 samples, respectively, via light microscopy from September 2001 through October 2005 (Wilde et al. 2005).

Oyster and clam exposure to *K. foliaceum* blooms was shown to have sublethal impacts on oyster and clam health based on increased lysosomal destabilization rates (Lewitus et al.

2003). *K. foliaceum* often blooms in humic-rich turbid water following rain events, and therefore the capability to use HMW DOM (a relatively labile component of humic matter) may select for this dinoflagellate over phytoplankton that have a greater reliance on photoautotrophic nutrition. In laboratory experiments, bloom populations and cultures of *K. foliaceum* exhibited high capabilities for rapid ingestion of high molecular weight dissolved organic matter, demonstrating the potential ability of *K. foliaceum* to form blooms in response to humic-rich loads.

The Florida red tide dinoflagellate *Karenia brevis* (formerly *Gymnodinium breve*) has been associated with massive fish and marine mammal mortality events in the Gulf of Mexico (Flewelling et al. 2005). *K. brevis* produces brevetoxin, which is accumulated in plant, fish, and shellfish tissues (Flewelling et al. 2005). The toxin metabolites are persistent in shellfish, leading to potential risks to human health (Bottein-Dechraoui et al. 2007). This species is not typically found in South Carolina waters.

Raphidophytes

Raphidophyte HAB species associated with SC fish kills include *Heterosigma akashiwo, Chattonella subsalsa, Chattonella cf. verruculosa*, and *Fibrocapsa japonica*. These raphidophyte species were nearly ubiquitous in brackish ponds surveyed on Kiawah Island (Lewitus et al. 2003, 2004). In a pre-development survey of the island by Zingmark (1975), these same species were not among the 240 phytoplankton taxa identified.

AEL surveillance and response efforts have revealed the widespread occurrence of raphidophyte blooms in brackish lagoonal ponds. From 2001-2005, raphidophytes were found in 40% of 1502 pond site samples collected, and in 61 of 87 ponds sampled. Samples with high raphidophyte abundances were common, encompassing 28 different ponds, and raphidophytes

frequently dominated phytoplankton community biomass. Raphidophyte blooms were common in the spring through summer, but rare during the winter. On 29 April 2003, an extensive bloom of *Heterosigma akashiwo* was observed offshore of Bulls Bay, SC, following a March-April Santee-Cooper freshwater rediversion. The bloom extended 8 km offshore, and the spatial extent was estimated at ca. 207 km^2 based on aerial observations and satellite imagery. More than 10,000 dead fish were estimated in the bloom area.

The Bulls Bay bloom, and a subsequent *H. akashiwo* bloom in Shem Creek, SC, were also found to cause physiological stress (lysosomal destabilization) in oysters, similar to those caused by *H. akashiwo* cultures (Keppler et al. 2005). The health of the oysters did not recover even after a 7-day depuration period. These findings have implications for possible long-term effects on oyster reproductive capability even after short-term (48 hr) exposure (Wilde et al. 2005).

Tidally influenced stormwater detention ponds sampled by the SCDNR-AEL range in salinity from low brackish to marine, and not surprisingly, the type of HAB is associated with salinity properties. In general, dinoflagellate and raphidophyte blooms were relatively prevalent under mid-brackish to marine conditions (Lewitus et al. 2003, 2004). Four raphidophyte species were nearly ubiquitous in mid- to high-brackish ponds, *Heterosigma akashiwo*, *Chattonella subsalsa*, *C. cf. verruculosa*, and *Fibrocapsa japonica*. Although salinity and temperature ranges generally overlapped, *F. japonica* was not found in waters < 10 ppt or < 22.6°C, and *H. akashiwo* did not occur in waters > 30 ppt (Lewitus et al. 2004).

The raphidophytes *Heterosigma akashiwo*, *Fibrocapsa japonica*, and *Chattonella subsalsa* have been implicated in numerous fish kills globally, with a particular impact on aquaculture. To understand the parameters that govern their growth, the SCDNR-AEL tested the

effects of trace metals and fecal extracts on the growth of *H. akashiwo*. Results from trace metal additions indicated a high iron requirement for this species. The fecal extract was also found to stimulate growth of *H. akashiwo*, suggesting that sources of iron (e.g. fertilizer) and fecal material (e.g. sewage, wildlife or pet excreta) may be stimulatory factors in raphidophyte bloom formation and/or maintenance.

HAB, Bacterial, and Viral Interactions

Bacteria and viruses have been shown to have complex interactions with HABs. Researchers have identified both algicidal bacteria and algal growth promoting bacteria (Doucette et al. 1998, Doucette et al. 1999, Liu et al. 2008a, 2008b, Mayali & Doucette 2002, Roth 2005). The SCDNR-AEL is currently investigating the role that viruses play in the microbial ecology of stormwater detention ponds. The field of environmental viral ecology is a relatively new one, and many habitats, both terrestrial and aquatic remain unexplored. In addition to direct effects of viruses on HAB forming phytoplankton, they are studying the effects of viruses on other members of the plankton that may themselves affect HAB formation (e.g. algal growth promoting bacteria). It is hypothesized that viruses can not only affect algal population directly (through infection) but indirectly through regulation of other algistatic microbes (e.g. algicidal bacteria). These studies will not only provide important ecological data on microbial dynamics, but also have the potential to provide organisms useful for future mitigation strategies.

Conclusions and Data Gaps

In summary, high nutrient concentrations, high chlorophyll a concentrations, and the presence of HABs are common conditions in Southeastern coastal stormwater ponds. These conditions lead to additional problems such as fish kills (either directly due to algal toxins, or

indirectly due to depleted oxygen when blooms degrade), negative health effects on aquatic organisms (for example, the Eastern oyster), and human health risks due to algal toxin exposure. Long-term monitoring and fish kill response efforts in 45 brackish detention ponds along the SC coast revealed the widespread and common occurrence of harmful algal blooms (HABs) (Kempton et al. 2002b, Lewitus & Holland 2003, Lewitus et al. 2003, 2004). All of the observed HABs have precedence for toxicity and/or causing fish kills (Landsberg 2002). Researchers have also found that stormwater ponds with tidal exchange are a source of excess nutrients and harmful algal blooms inputs to adjacent coastal waters (Lewitus et al. 2003, Drescher 2005, Brock 2006).

The problem of cultural eutrophication is well-established, and management solutions have been prescribed (Paerl 2006). Nutrient inputs from atmospheric and groundwater sources are not as well characterized, although groundwater has been identified as a major route of nutrient transport in coastal soils (Vandiver-Hayes 2005). Actions to control nutrient inputs, such as the use of vegetative buffers, can be effective in reducing nutrient runoff (USES 2004, Vandiver-Hayes 2005, Serrano & DeLorenzo 2007).

The knowledge of how prevalent HABs are in stormwater ponds and what water quality conditions favor particular types of HABs is now fairly extensive (Wilde et al. 2005). Additional research into the non-target effects of algal toxins on aquatic life is needed, as well as studies of the accumulation of algal toxins in fish and shellfish species. The linkages between bloom dynamics and toxicity are not well understood.

Technological advancements are needed to better predict, measure, and respond to HABs. Standard assays have been developed for detecting PSP toxins, brevetoxins and okadaic acid (Anderson et al. 2001, Maucher et al. 2007); microcystins, anatoxins and saxitoxins (Chorus &

Bartram 1999, Carmichael et al. 2001, Nicholson & Burch 2001). Some toxins can be measured using rapid assays, however most still require costly and time-consuming analytical chemistry methods. We have not yet identified many algal toxins. Algal toxins typically require more than a decade to characterize, and appropriate standards for routine analysis and detection are not yet available for all algal toxins (Burkholder et al. 2005). Once detection methods are available, there needs to be guidelines for the HAB toxins in surface waters. The WHO (1999) has established a safety threshold of 1 μg/L for microcystin in drinking water, but there are not surface water quality criteria for microcystin or the many other algal toxins.

Predicting HABs is a complex process for many reasons. Algal cysts are transported between the sediments and the water column, some organisms have alternate reproductive strategies and multiple life stages, and trace amounts of rare elements may trigger a bloom. Continued experimentation with algicidal bacteria and viruses is needed to elucidate microbial interactions that may be useful in understanding HAB initiation and termination mechanisms. The formation of HABs is often not reproducible; that is they often fail to appear under what seem to be the same circumstances in which they appeared previously. It is, therefore, difficult to identify important causal factors and to build robust predictive models. Post-hoc modeling of HAB events can be informative (e,g, Silvert and Cembella 1999), and various mathematical models have been proposed (e.g. Chattopadhyay et al. 2002), but these are mostly limited spatially to a given location. Franks (1997) provides a review of HAB models. Real-time observations are essential for effective short-term operational forecasting of HABs (e.g. satellite imagery data of algal pigments), but predictive modeling systems still need to be developed. The HAB Forecasting System provided by NOAA has had some success predicting the location, extent, and potential for development or movement of harmful algal blooms in the Gulf of

Mexico. This forecasting system uses a combination of satellite imagery, field observations, and buoy data.

NOAA, CCEHBR is collaborating with other federal, state and local agencies to develop a South Carolina Environmental Surveillance Network that would provide real-time surveillance and reporting of environmental incidents such as fish kills, bird kills, animal disease outbreaks, harmful algal blooms, marine mammal strandings, etc. The program would notify participating network science and regulatory experts of mortality incidents; allow for quick assessments of potential links between and among mortalities and provides a mechanism to alert the emergency management community of incidents that could impact commerce and public health. Through this program, data that were previously viewed independently could hence be considered collectively, perhaps improving our understanding of the interactions between water quality conditions and the occurrence of harmful algal blooms.

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