Industrialized Animal Production—A Major Source of Nutrient and Microbial Pollution to Aquatic Ecosystems

Michael A. Mallin
Lawrence B. Cahoon
University of North Carolina at Wilmington

Livestock production has undergone massive industrialization in recent decades. Nationwide, millions of swine, poultry, and cattle are raised and fed in concentrated animal feeding operations (CAFOs) owned by large, vertically integrated producer corporations. The amount of nutrients (nitrogen and phosphorus) in animal manure produced by CAFOs is enormous. For example, on the North Carolina Coastal Plain alone an estimated 124,000 metric tons of nitrogen and 29,000 metric tons of phosphorus are generated annually by livestock. CAFO wastes are largely either spread on fields as dry litter or pumped into waste lagoons and sprayed as liquid onto fields. Large amounts of nitrogen and phosphorus enter the environment through runoff, percolation into groundwater, and volatilization of ammonia. Many CAFOs are located in nutrient-sensitive watersheds where the wastes contribute to the eutrophication of streams, rivers, and estuaries. There is as yet no comprehensive Federal policy in place to protect the environment and human health from CAFO generated pollutants.

KEY WORDS: swine; poultry; nutrients; pathogens; eutrophication.

INTRODUCTION

Humans first domesticated a number of animal species in several regions of the world ca. 4–6,000 years ago (Diamond, 1997). Early domes-

Please address correspondence to Michael Mallin, Center for Marine Science, University of North Carolina at Wilmington, Wilmington, NC 28409; mallinm@uncwil.edu.

tication of animals allowed humans to exploit their abilities to convert otherwise inaccessible resources into useful products and services. Animal production was necessarily resource-limited and since production was tightly coupled to the productivity of the landscape, animal waste production would seldom have exceeded the assimilation capacity of the landscape.

In recent decades livestock production, particularly that of swine, cattle and poultry, has undergone a major change toward industrialization. The industrialization of the cattle and poultry industries began in the late 1950s while industrialization of swine production began in the 1970s (Thu & Durrenberger, 1998). Industrialization of livestock production basically consists of moving animals from pastures and lots into large buildings, where they are confined and fed throughout their lives until they are ready for market. Adoption of confined feeding techniques, together with the availability of large quantities of feedstuffs and efficient transportation systems, now allow animal producers to circumvent the ecological constraints otherwise imposed by the landscape. As a consequence, animal waste production often exceeds the assimilatory capacity of the landscape both locally and regionally.

Individual concentrated animal feeding operations (CAFOs) now house hundreds to thousands of animals in each confinement structure, and vast amounts of animal waste are generated by these facilities. Swine waste is deposited on the floor of the structures by the animals, where it is periodically washed between slats in the floor into a system of trenches and pipes beneath the buildings. From there it is conveyed outside and into a cesspit called a "waste lagoon." Some anaerobic treatment occurs in the lagoon and the liquid waste is periodically applied on surrounding fields by surface spraying, surface spreading, or in some cases subsurface injection. Crops planted on the fields, such as Bermuda grass, cotton, corn, and soy take up some of the plant nutrients in the waste material. Some poultry CAFOs utilize the lagoon system, but the majority of poultry CAFOs dispose of dry litter on the fields (Williams et al., 1999). In any case, concentrated waste material is spread onto fields, from where it can enter the environment through surface runoff or groundwater infiltration (Edwards & Daniel, 1992; Mallin, 2000). Thus, individual CAFOs represent an ecologically anomalous concentration of animals whose waste production can easily exceed the assimilatory capacity of the local landscape.

Regional concentrations of CAFOs create circumstances in which very large imbalances of waste production versus waste assimilation capacity can arise (Barker and Zublena, 1995; Jackson et al., 2000). The use of carefully formulated feeds, the need for large amounts of these feeds, and transportation cost considerations have led to the regional concentration of CAFOs around feed mills and meat packing facilities (C. Wright, personal communication). Swine CAFOs are abundant on the North Carolina Coastal Plain, and in Midwestern states such as Iowa, Minnesota, Michigan, and Indiana, and are moving into western areas such as Utah and Colorado (Thu & Durrenberger, 1998). Poultry CAFOs are abundant in Iowa, Arkansas, Georgia, Maryland, Virginia, Delaware, North Carolina, California, and Mississippi (Edwards & Daniel, 1992). Cattle CAFOs are rare on the east coast but common in Texas and several midwestern states. The environmental challenge of regional concentration has been recognized explicitly for some time, e.g., in legislation introduced by Sen. Harkin (D-Iowa) in 1997 (the Animal Agriculture Reform Act, S.B. 1223). Sen. Harkin (1997) cited the Department of Agriculture as reporting: "The continued intensification of animal production systems without regard to the adequacy of the available land base for manure recycling presents a serious policy problem."

CAFOs have also had many acute pollution problems with their waste disposal systems, including lagoon ruptures and major leaks caused by mismanagement or weather (Mallin, 2000). For example, 25 million gallons of liquid swine waste entered North Carolina's New River and its estuary following a waste lagoon rupture in 1995, polluting 22 miles of the river and much of the upper estuary. The pollution load caused freshwater and estuarine fish kills and algal blooms, and polluted the river and its sediments with fecal bacteria for months (Burkholder et al., 1997). That same year a poultry lagoon breach and a large swine waste lagoon leak also caused algal blooms, fish kills, and microbial contamination in North Carolina's Cape Fear River basin (Mallin et al., 1997). In all of these cases large quantities of nutrients (nitrogen and phosphorus) entered downstream water bodies from the CAFO sites. Major CAFO accidents have also occurred in Iowa, Maryland, and Missouri (Thu & Durrenberger, 1998; Mallin, 2000). While the acute pollution caused by CAFOs is well documented, the sheer magnitude of their distribution and abundance merits an examination of the chronic effects that these facilities may have on our water resources.

North Carolina presents an excellent example of the effects of rapidly increasing industrialized livestock production, particularly that of swine. Industrialization of North Carolina's swine production began in the 1980s, and continued rapidly until the mid to late 1990s (Burkholder et al., 1997). The lagoon waste disposal system was deployed with little foresight for the environmental consequences, and CAFOs were constructed with little regulation until lagoon construction standards, siting regulations, and waste management plans were legally required in 1993 (Burkholder et al., 1997).

A moratorium on new CAFO production was begun in 1997; however, this did not take full effect until nearly 10,000,000 head of swine were present in eastern North Carolina, the vast majority in CAFOs (Burkholder et al., 1997; Mallin, 2000).

This large number of swine (currently exceeding the North Carolina human population of 7,900,000), as well as poultry and cattle, requires vast amounts of animal feed, which contains nitrogen (N) and phosphorus (P), nutrients that can lead to the eutrophication of water bodies (Carpenter et al., 1998; Correll, 1998; Cahoon et al., 1999; Glasgow & Burkholder, 2000; Mallin, 2000). Cahoon et al. (1999) noted that as of 1995 the animal production industry in North Carolina's Cape Fear River basin produced some 82,700 metric tons of N and 26,000 metric tons of P as waste in this watershed. Glasgow and Burkholder (2000) computed that in 1998 North Carolina's Neuse River watershed received 41,000 metric tons of N and 16,000 metric tons of P from CAFOs in that basin. Since the vast majority of feed for swine and poultry is shipped into these watersheds from midwestern states (Thu & Durrenberger, 1998; Cahoon et al., 1999), most of the nutrients added to the watershed through animal manures are considered "new" nutrients, imported into the system rather than recycled within it. The purpose of this paper is to describe the magnitude of industrialized animal production in a large region of the North Carolina Coastal Plain (see Figure 1), assess the potential contribution of nutrients and microbial pollution to this region, and describe the realized and potential effects of this pollutant load.

METHODS

An assessment of animal waste contributions to pollutant loads on the North Carolina Coastal Plain required computation of livestock numbers by animal category in the region, and estimates of the amount of N, P, and bacteria excreted by each species of livestock on an annual basis. The Coastal Plain contains over 90% of the State's swine population, the vast majority of its turkeys, and about 30% of the chicken population. For each of the 38 counties in the region, the most recent available data on annual production of several types of livestock (swine, broiler chickens, other chickens, turkeys, and cattle) were obtained from the website of the North Carolina Department of Agriculture (NCDA, http://www.agr.state.nc.us/stats/cntysumm). On an annual basis, there are approximately 2.9 turkey generations (cohorts) and 6.5 broiler chicken generations produced. Thus, the turkey and broiler production figures provided on the NCDA website for each

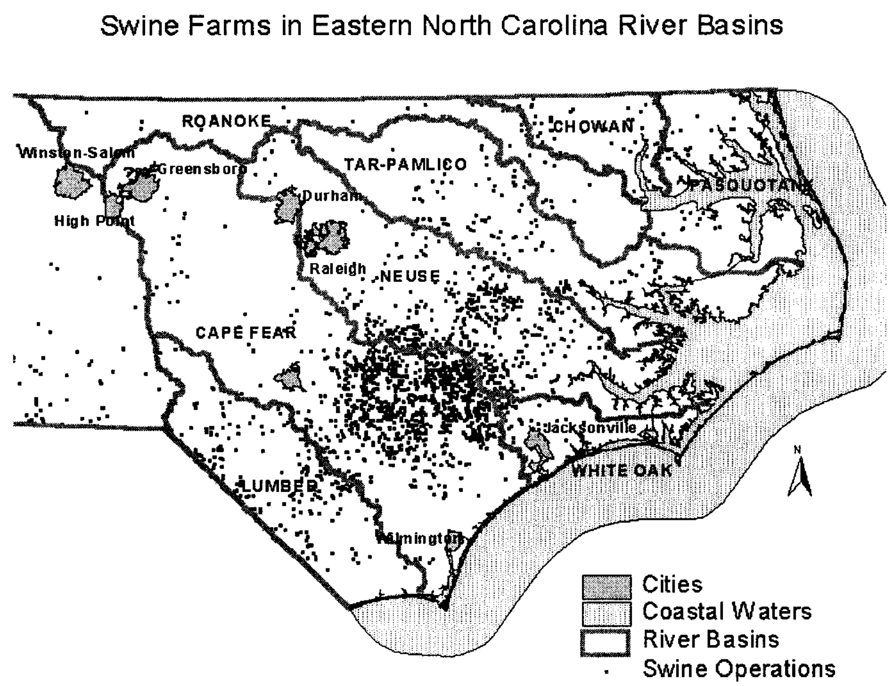

FIGURE 1. Location of swine CAFOs (operations with 250 or more head) on the North Carolina Coastal Plain by river basin.

county were divided by these numbers to yield average annual standing stock (total animals present at any one time), and subsequent annual manure production.

Animal waste N and P production rates were calculated using recent published information or data from industry sources. Swine waste N and P contents were calculated using data supplied by T. van Kempen (North Carolina State University): 15.9 kg N/yr and 5.3 kg P/yr for sows, 11.1 kg N/yr and 2.3 kg P/yr for grower-finisher pigs, and are similar to those reported elsewhere, e.g., Powers and Van Horn (1998). Total swine N and P excretion rates were then calculated using the proportion of sows and grower-finisher pigs (0.103 and 0.897, respectively in 1998 (NCDA, 1999). Turkey and broiler chicken N excretion were calculated using data from Powers and Van Horn (1998); they report N excretion as 0.395 kg N/turkey produced and 0.017 kg N/broiler produced. Using N:P ratios of 3.57:1 for turkey waste and 3.23:1 for broiler chicken waste (NRCS, 1996, Chapter

4), P excretion was calculated as 0.11 kg P/turkey produced and 0.0053 kg P/broiler produced. Annual N and P excretion rates for cattle were calculated as in Cahoon (1999), using estimates of 46.8 kg N/cow and 11.7 kg P/cow.

The Lower Cape Fear River Program at the University of North Carolina at Wilmington has collected nutrient data at 35 locations located throughout the Cape Fear River basin since 1995. Published data for a station in the Northeast Cape Fear River near the town of Sarecta (GPS coordinates N34 43.365, W77 51.752) are presented below. These data are of interest because of that station's proximity to numerous CAFOs (see Figure 1). Since ammonium volatilization is most active during warm months (NCDAQ, 1997), summertime (May–September) ammonium data are presented for a six-year period from 1996 through 2001.

Estimates of fecal coliform bacteria excreted on a daily basis for several of the livestock species were obtained from Sobsey (1996). Based on this reference the following fecal coliform bacterial daily production figures were used for pigs (1.2×10^{10} colony-forming units (CFU)), chickens (1.4×10^{8} CFU), and cows (6.0×10^{9} CFU).

RESULTS

The North Carolina Coastal Plain produces large numbers of swine, broiler chickens, and turkeys, and smaller but significant numbers of other chickens and cattle (Table 1). Swine production in North Carolina is second

TABLE 1

Population of Livestock by Category on the North Carolina Coastal Plain, 2000–2001 (About 6.5 generations of broilers and 2.9 turkey generations are produced per year. Dividing broiler chicken and turkey production by these factors provides standing stock, or numbers present at any one time on the Coastal Plain.)

Animal Category	Numbers Used in Nutrient Calculations
Swine	8,700,000 (standing stock)
Broiler chickens	210,000,000 (produced)
Other Chickens	3,480,000 (produced)
Turkeys	31,800,000 (produced)
Cattle	149,000 (standing tock)

in the United States only to Iowa (Burkholder et al., 1997; USNASS, 1997). North Carolina ranks fourth in the United States in broiler chickens sold, and first in the United States in turkeys sold (USNASS, 1997). The vast majority of the swine and poultry are in CAFOs, whereas many of the cattle are grazed on open lands.

Our computations show that swine and turkey production contribute the greatest amount of N and P in the annual waste stream (Table 2). Swine alone generate 101,000 metric tons of N and turkeys 12,600 metric tons. Swine also generate 22,700 tons of P and turkeys 3,500 metric tons. Thus, swine are by far the largest producers of nutrients in comparison with other livestock on the Coastal Plain, and the manner of their waste disposition deserves attention. Swine waste from CAFOs is invariably pumped into lagoons, some of which are located on river floodplains. In North Carolina liquid waste from the lagoons is typically then sprayed out on adjoining fields, from which surface drainage to waterways or subsurface drainage to groundwaters can occur. The nutrients produced by poultry CAFOs as manure are largely spread as dry litter on fields, with some pumped into waste lagoons, from which they are sprayed as liquid waste onto fields. Secondary treatment of livestock waste for nutrient removal is seldom practiced.

This analysis does not take into account nutrients produced by the decomposition of dead animals. Following Hurricane Floyd in October 1999, the news media published numerous photographs of drowned swine and poultry from CAFOs in areas inundated by floodwaters. The numbers of drowned livestock may have been very large, as Wing et al. (2002) determined that 241 CAFOs were within the geographical coordinates of the areas inundated by post-Floyd floodwaters according to satellite imagery.

TABLE 2

Estimated Amounts of Nitrogen and Phosphorus (metric tons) Excreted Annually by Various Livestock Categories on the North Carolina Coastal Plain, 2000–2001

Animal Category	Nitrogen	Phosphorus
Swine	101,000	22,700
Broiler chickens	3,570	1,110
Other Chickens	60	20
Turkeys	12,600	3,500
Cattle	7,000	1,750
Grand Total	124,230	29,080

N.C. Department of Agriculture statistics report over 1 million swine mortalities per year as of 1998, not counting piglets lost (N.C. D.A., 1999); thus, animal carcasses are likely another significant source of nutrients to the environment.

Data published by the Lower Cape Fear River Program (available at the website http://www.uncwil.edu/cmsr/aquaticecology/laboratory/lcfrp) demonstrate that there was a statistically significant increase in ammonium levels at a Northeast Cape Fear River station (Sarecta) during the period 1996–2001 (see Figure 2). Ammonium comprises the largest portion of total N in swine and poultry liquid waste (Burkholder et al., 1997; Mallin et al., 1997; Williams et al., 1999). Along with transport of ammonium in runoff or subsoil movement, it can be volatilized and transported in the gaseous ammonia form (Edwards & Daniel, 1992; Williams et al., 1999; Mallin, 2000). The station at Sarecta has 344 swine CAFOs within a 20 km radius, and 587 swine CAFOs within a 30 km radius (we have no data on poultry CAFOs). This station likely receives ammonium inputs from overland runoff and lateral groundwater flow, and airborne deposition. The implications of nutrient increases to downstream waters are discussed below.

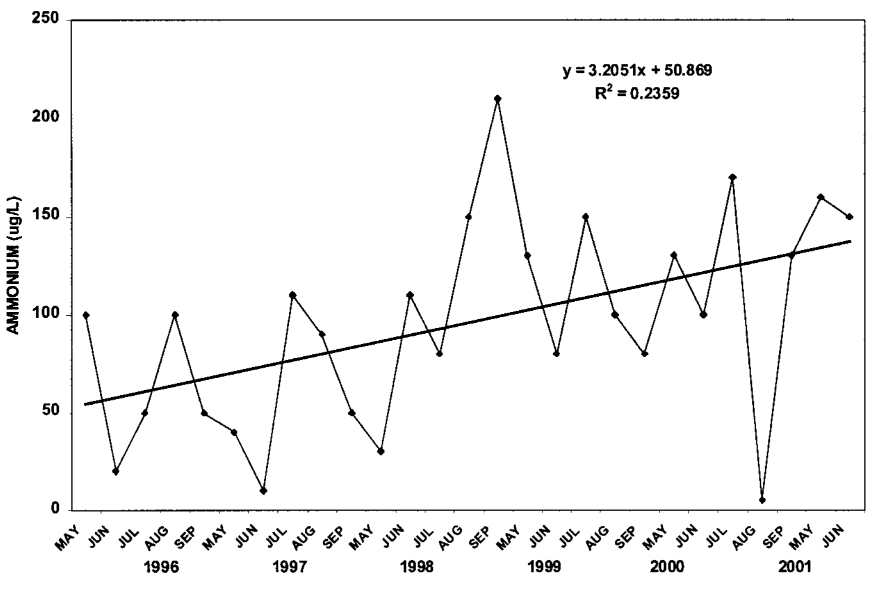

FIGURE 2. Summer ammonium concentrations at Sarecta, a water quality station on the Northeast Cape Fear River in a location near numerous CAFOs, data from 1996 to 2001.

Applying Sobsey's (1996) conversion factors figures to livestock populations on North Carolina's Coastal Plain yields estimated annual excretion of fecal coliform bacteria of 3.8×10^{18} from swine, 1.7×10^{18} CFU from broilers, 1.8×10^{17} from other chickens, and 3.3×10^{17} from cattle.

DISCUSSION

Fate of Excreted Nutrients

As mentioned earlier, major storms and accidents are documented mechanisms by which large amounts of nutrients have been abruptly transported from CAFOs to receiving waters (Burkholder et al., 1997; Mallin et al., 1997; 1999; Mallin, 2000). However, CAFOs also chronically export nutrients to water resources through several means. Normal rain events carry nutrients from swine sprayfields to nearby streams through surface and subsurface runoff (Evans et al., 1984; Westerman et al., 1987) where these inputs have caused stream nitrate-N to rise above 5 mg N/L and P above 1 mg P/L (Stone et al., 1995; Gilliam et al., 1996). Nutrients, mainly nitrate and ammonium, also leach downwards into groundwater from animal waste lagoons, sprayfields, and litter fields. In a set of 11 North Carolina swine lagoons, Huffman and Westerman (1995) found average inorganic (ammonium and nitrate) N concentrations of 143 mg/L in nearby groundwater, and found that through leakage the lagoons exported on average 4.7 kg N/day to groundwater. Also in North Carolina Westerman et al. (1995) found average concentrations of ammonium in downslope well fields that exceeded 50 mg N/L, compared with upslope wells that were less than 1 mg N/L. The nitrate form of N is especially mobile in soils and can pass readily through soils to contaminate groundwater. Liebhardt et al. (1979) found high levels of nitrate in soil groundwater beneath Delaware cornfields where poultry waste was applied as the sole fertilizer, with evidence that the nitrate moved laterally toward a nearby stream. Using nitrogen isotopic techniques Karr et al., (2001) have traced nitrate generated from swine waste spray fields through shallow groundwater into receiving stream waters, and at least 1.5 km downstream. Phosphorus is much less mobile, and binds readily to soil particles. However, when the P content of soils is built up dramatically through excessive manure application, both surface export and subsurface loss of P occurs (Sharpley et al., 1999).

Anaerobic treatment of swine wastes with high concentrations of organic N promotes deamination, resulting in high concentrations of ammonium-N in lagoon liquid. Liming is used to maintain a pH above about 7, favoring ammonia formation. Ammonia volatilizes from sprayfields and waste lagoons, and is transported downwind (McCulloch et al., 1998; Aneja et al., 2000; Walker et al., 2000). The North Carolina Department of Air Quality estimates that 70–80% of all swine waste N and a somewhat lesser percentage of poultry waste N is thus volatilized (N.C. D.A.Q., 1997). It is notable that the Neuse River watershed, which contains approximately 25% of North Carolina's swine population and numerous poultry production facilities and is downwind of a large concentration of CAFOs in the Cape Fear watershed, registered a 14% increase in total N and a 34% increase in nitrate over the seven year period 1990–1997 (Glasgow & Burkholder, 2000). While other anthropogenic sources of N undoubtedly contributed to this loading, the large recent rise in CAFOs in those watersheds would suggest that animal production is a significant cause of these nutrient inputs. Walker et al. (2000) and Mallin (2000) have documented a trend of increasing ammonium deposition in the coastal region of North Carolina, which they attribute to animal production sources. At Sarecta on the Northeast Cape Fear River a steady rise in river ammonium concentrations from 1996–2001 is evident (see Figure 2). There are no new or large wastewater treatment facilities in that area that can account for this increase. The single major land use change in that area has been the rapid proliferation of CAFOs during the 1980s and 1990s (see Figure 1).

Potential Impacts on Water Resources

Kellogg (2000) prioritized U.S. watersheds in terms of vulnerability to manure nutrient contamination based on a number of factors, including soil percolation, soil runoff potential, soil erosion potential, and amount of animal nutrients applied to soils. Much of the North Carolina Coastal Plain, especially the Albemarle-Pamlico and Cape Fear watersheds, ranked highest in the nation in vulnerability. Many of the surface water supplies downstream of CAFO-dense areas on the North Carolina Coastal Plain (Figure 1) are sensitive to N and/or P loading, and will respond by formation of algal blooms (Rudek et al., 1991; Paerl et al., 1990; Glasgow & Burkholder, 2000). This is especially true in the Neuse, Pamlico, and New Rivers and their estuaries (Dame et al., 2000; Mallin et al., 2000). Algal blooms can build up high concentrations of biomass, and eventually die and become a source of labile organic material. Bacteria feed on this biomass and multiply, creating high biochemical oxygen demand (BOD) that will at times lower dissolved oxygen concentrations to levels that can kill sessile bottom organisms and create areas in which finfish cannot survive—a loss of usable habitat. Another impact of increased nutrient loading on estuaries is to stimulate growth of the toxic dinoflagellates *Pfiesteria piscicida* and *P. shumwayae*, which have bloomed downstream of CAFO areas in the Neuse, Pamlico, and New River Estuaries of North Carolina and the Chesapeake Bay in Maryland (Burkholder et al., 1995; Burkholder & Glasgow, 1997; Glasgow et al., 2001). Growth of *P. piscicida* is more stimulated by P loading whereas *P. shumwayae* appears to be more stimulated by N inputs (Glasgow et al., 2001). Both species of *Pfiesteria* have caused many fish kills in North Carolina and some in Maryland, as well as human health problems to researchers and watermen exposed to its toxins (Burkholder et al., 1995; Burkholder & Glasgow, 1997; Burkholder & Glasgow, 2001). Blooms of these organisms and consequent fish kills have led to closures of areas in the Chesapeake Bay region and the Albemarle-Pamlico estuarine region in North Carolina to commercial fishing, due to health concerns over the consumption of affected fish and exposure to airborne *Pfiesteria* toxins when on the water (Burkholder & Glasgow, 2001).

In the Cape Fear River basin, which produces 50% of North Carolina's swine and vast numbers of poultry, most of the CAFOs are in watersheds drained by blackwater streams. These are streams that drain lowland forests and riverine swamps, and in pristine condition are naturally nutrient poor. Recent experiments have been conducted on the response of blackwater streams to increased nutrient loading (Mallin et al., 2001). These experiments showed that N inputs of 1 mg/L led to spring and summer algal blooms in test waters, while P levels of 1 mg/L caused significant production of heterotrophic microbes and increased biochemical oxygen demand (Mallin, 2000; Mallin et al., 2000; Mallin et al., 2001). Since recent assessments (Figure 2) show a steady increase in ammonium in certain downstream locations in the Cape Fear basin, this loading has the potential for degrading water quality in areas receiving nutrient inputs.

Seagrass beds are an important coastal habitat for many species of finfish and shellfish. Historically, important seagrass habitat has been located downstream of CAFO-rich areas in the Albemarle-Pamlico estuarine system in North Carolina as well as the Chesapeake Bay. Much of that habitat disappeared in the mid-to-late 1900s. A number of factors can cause losses of seagrass, including reduced photosynthesis from increased turbidity (Dennison et al, 1993). However, the most important seagrass species on the mid-Atlantic seaboard (eelgrass—*Zostera marina*) has been shown to be sensitive to nitrate loading, and can die under prolonged exposure to nitrate concentrations of 50 to 100 µg N/L or higher (Burkholder et al., 1992; Burkholder et al., 1994). Some coastal North Carolina waters can periodically receive extended inputs of nitrate from upstream freshwater sources that exceed these critical levels (Mallin et al., 1993; Paerl et al., 1995; Mallin et al., 1999; Glasgow & Burkholder, 2000) thus providing a habitat stressful to eelgrass survival or re-establishment.

Animal Pathogens and Humans

Livestock are known to excrete many of the same pathogenic bacteria, viruses, and protozoans that can afflict humans. These organisms include pathogenic bacteria such as *Escherichia coli*, *Salmonella* spp., and *Streptococcus* spp., pathogenic protozoans such as *Giardia lamblia* and *Cryptosporidium parvum*, and a number of viruses (Mawdsley et al., 1995). The way animal waste is treated will affect pathogen survival and potential transmission to humans. Composting of manure raises temperatures high enough to kill most microbes, but animal waste slurries do not reach lethal temperatures (Mawdsley et al., 1995). Microbes in animal waste slurries such as lagoon liquid can survive for extended periods; *E. coli* has been known to survive up to 11 weeks in such an environment (Mawdsley et al., 1995). If waste is applied to the land surface survival time is cut to a matter of days, particularly under conditions of bright sunlight (Crane et al., 1983; Mawdsley et al., 1995). However, rain events occurring shortly after animal waste is surface-applied to fields cause vertical and horizontal movement of microbes to nearby water bodies (Crane et al., 1983; Mawdsley et al., 1995; Mallin, 2000). Large-scale microbial disease outbreaks have been traced to livestock vectors. In 1999 and 2000 the news media reported incidents in Albany, New York (MMWR 1999) and Walkerton, Ontario of mass illnesses and some deaths to humans that were exposed to pathogenic *E. coli* in water sources contaminated by runoff from cattle husbandry areas.

As indicated above, livestock on the Coastal Plain excrete large amounts of fecal bacteria in manure. Unlike human waste, microbes generated by CAFOs are not exposed to secondary treatment or chlorination to disinfect the material. When applied to fields in manure the vast majority of these microbes are likely deactivated by ultraviolet radiation, microbial competition and predation, or other means (Crane et al., 1983). However, because of the sheer volume of microbes deposited, there still remains a significant pollution potential from this material entering surface or groundwaters that humans will contact. If CAFO-generated microbes enter the sediments of water bodies, organisms such as *E. coli* can find a favorable environment where they can remain viable for over two months (Davies et al., 1995). For example, following a large swine waste lagoon spill in the New River, North Carolina, Burkholder et al. (1997) found fecal coliform bacterial counts ranging from 1,000,000 to 3,000,000 per 100 ml of river water several km downstream from the spill site. These very high concentrations declined to the range of 1,000 to 5,000 per 100 ml after 14 days, and to less than 1,000 per 100 ml in 61 days. However, further sampling indicated that the river sediments maintained concentrations of fecal bacteria up to 5,000 per 100 ml for 61 days. The risk of large quantities of fecal microbes entering the environment is thus high following acute CAFO mishaps; although the risk of human exposure to these microbes chronically through normal operations is yet undetermined.

Regulation

Point source discharges from municipal or industrial wastewater treatment plants are regulated under the National Pollution Discharge Elimination System (NPDES) enacted by the National Environmental Policy Act of 1971 (NEPA). This process authorizes the US Environmental Protection Agency or individual states to license and inspect dischargers, and set maximum pollutant discharge concentrations. However, CAFOs have been considered to be non-point source dischargers, and were thus exempt from this process. As such, regulation of pollutant discharges from them has been piecemeal and varies from state to state. Current legislated and regulatory controls on the environmental effects of CAFOs have generally followed demonstration of negative environmental impacts, rather than preventing them, e.g., Maryland's Water Quality Improvement Act of 1998. Laws and regulations in many states define CAFOs as farms and tacitly assume that CAFOs manage nutrients and other wastes as do conventional farms, when in fact CAFO operations depart significantly from the ecological relationships that control farm productivity (Jackson et al., 2000). Moreover, most laws and regulations address CAFOs as individual operations, thus neglecting the considerable effects of concentration of many CAFOs in relatively small regions.

Although some Federal legislators have shown concern for the environmental impacts of CAFOs (Harkin, 1997), comprehensive legislation designed to regulate CAFO-generated pollution has not yet occurred on the Federal level. Federal regulations have only recently recognized the need to limit P over-application in animal wastes; the U. S. Department of Agriculture's Natural Resource Conservation Service mandates soil P management in its most recent version of the Nutrient Management Standard 590 (Sharpley & Tunney, 2000). Implementation by the states is not uniform, however, as they utilize different soil test procedures, different risk assessment methods, and different remediation responses. North Carolina has just developed a Phosphorus Loss Assessment Tool (PLAT), which has not yet been fully implemented. However, these new regulations address only one aspect of the larger set of environmental challenges posed by CAFOs, and fail to address the consequences of regional concentration of CAFOs at all. Consequently, CAFOs present a major challenge to the current system of environmental law and regulations in the United States.

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