Science of the Total Environment 511 (2015) 676–683

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Source tracking swine fecal waste in surface water proximal to swine concentrated animal feeding operations

Christopher D. Heaney [a,b,*], Kevin Myers [c], Steve Wing [d], Devon Hall [e], Dothula Baron [e], Jill R. Stewart [c]

[a] Department of Environmental Health Sciences, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD, USA
[b] Department of Epidemiology, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD, USA
[c] Department of Environmental Sciences and Engineering, University of North Carolina, Chapel Hill, NC, USA
[d] Department of Epidemiology, University of North Carolina, Chapel Hill, NC, USA
[e] Rural Empowerment Association for Community Help (REACH), Warsaw, NC, USA

HIGHLIGHTS

- We studied the sanitary quality of surface water proximal to swine CAFOs.
- Fecal indicator bacteria levels suggest poor water quality proximal to swine CAFOs.
- Swine-specific Bacteroidales were more prevalent proximal down- vs proximal upstream.
- Swine-specific Bacteroidales can help track fecal waste proximal to swine CAFOs.

ARTICLE INFO

Article history:
Received 28 October 2014
Received in revised form 18 December 2014
Accepted 19 December 2014
Available online 17 January 2015

Editor: D. Barcelo

Keywords:
Swine
Concentrated animal feeding operation
Fecal pollution
E. coli
Enterococcus
Microbial source tracking
Run-off
Water quality

ABSTRACT

Swine farming has gone through many changes in the last few decades, resulting in operations with a high animal density known as confined animal feeding operations (CAFOs). These operations produce a large quantity of fecal waste whose environmental impacts are not well understood. The purpose of this study was to investigate microbial water quality in surface waters proximal to swine CAFOs including microbial source tracking of fecal microbes specific to swine. For one year, surface water samples at up- and downstream sites proximal to swine CAFO lagoon waste land application sites were tested for fecal indicator bacteria (fecal coliforms, *Escherichia coli* and *Enterococcus*) and candidate swine-specific microbial source-tracking (MST) markers (*Bacteroidales* Pig-1-Bac, Pig-2-Bac, and Pig-Bac-2, and methanogen P23-2). Testing of 187 samples showed high fecal indicator bacteria concentrations at both up- and downstream sites. Overall, 40%, 23%, and 61% of samples exceeded state and federal recreational water quality guidelines for fecal coliforms, *E. coli*, and *Enterococcus*, respectively. Pig-1-Bac and Pig-2-Bac showed the highest specificity to swine fecal wastes and were 2.47 (95% confidence interval [CI] = 1.03, 5.94) and 2.30 times (95% CI = 0.90, 5.88) as prevalent proximal down- than proximal upstream of swine CAFOs, respectively. Pig-1-Bac and Pig-2-Bac were also 2.87 (95% CI = 1.21, 6.80) and 3.36 (95% CI = 1.34, 8.41) times as prevalent when 48 hour antecedent rainfall was greater than versus less than the mean, respectively. Results suggest diffuse and overall poor sanitary quality of surface waters where swine CAFO density is high. Pig-1-Bac and Pig-2-Bac are useful for tracking off-site conveyance of swine fecal wastes into surface waters proximal to and downstream of swine CAFOs and during rain events.

1. Introduction

Hog production in the United States (US) has shifted from numerous small family farms to fewer large vertically integrated concentrated animal feeding operations (CAFOs) (MacDonald and McBride, 2009; Reimer, 2006). In North Carolina (NC) between 1991 and 1998, the number of swine increased from 3.7 million to over 10 million, placing NC as the second leading state in US pork production (Edwards and Ladd, 2000). Since 1998, NC has remained the second leading US pork producer with recent total hog and pig inventory estimates ranging mostly between 8 to 9 million (NCDACS, 2012; USDA, 2007, 2012, 2013, 2014). Swine CAFOs are disproportionately located in the eastern coastal plain region of NC (Wing et al., 2000) and house large numbers of animals whose waste is collected and stored in open-pits called lagoons before the liquid waste is sprayed onto agricultural fields.

* Corresponding author at: Department of Environmental Health Sciences and Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Johns Hopkins University, 615 North Wolfe Street, Room W7033B, Baltimore, MD 21205 USA.
E-mail address: cheaney1@jhu.edu (C.D. Heaney).

http://dx.doi.org/10.1016/j.scitotenv.2014.12.062
0048-9697/

According to 2012 county-level estimates of the North Carolina Department of Agriculture and Consumer Services, the top five NC hog-producing counties (Duplin, Sampson, Bladen, Wayne, and Jones) are contiguous and have a population of over 5.6 million swine (NCDACS, 2012). Government officials, agricultural experts, and neighbors of swine CAFOs have expressed concern that this scale of swine production and the associated quantity of manure produced in a small area of land could lead to over-application to agricultural fields and off-site conveyance of fecal pollution and contamination of surface waters (USGAO, 2008).

The NC Department of Environment and Natural Resources (NCDENR) permits swine CAFOs as non-discharge facilities. Swine CAFO permits and regulations include nutrient management plans for the application of liquid waste according to agronomic rates of nutrient uptake of crops grown on the permitted land application spray fields (Edwards and Ladd, 2000; NCGA, 1995). However, questions remain about whether fecal pollution from swine CAFOs in NC can be conveyed off-site of permitted spray fields and whether there are impacts on the sanitary quality of surface waters proximal to swine CAFOs (Jongbloed and Lenis, 1998; Krapac et al., 2002; Thurston-Enriquez et al., 2005).

In 2012, Duplin County, NC had an estimated swine population of 2,040,000 and an estimated poultry population (broiler and other meat-type chickens as well as turkeys) of 88,500,000 (NCDACS, 2012). Because sources of fecal contamination of surface water can be diverse – with numerous potential animal and human inputs – better tools and technologies are needed to track species-specific sources of fecal wastes. Microbial source tracking (MST) methods are designed to improve the identification of sources of fecal contamination (Boehm et al., 2013; Dancer et al., 2014; EPA, 2005). Several candidate swine-specific fecal MST markers have been proposed (Mieszkin et al., 2009; Okabe et al., 2007; Ufnar et al., 2007) with variable specificity and unresolved questions about the generalizability of the markers in different geographic locations (Santo Domingo et al., 2007; Stewart et al., 2013). Application of the proposed microbial source tracking markers to help evaluate management practices in agricultural watersheds has also been limited, although studies in Ontario have used *Bacteroidales* markers to assess livestock exclusion practices (Wilkes et al., 2013) and to compare tile drainage management techniques (Wilkes et al., 2014). Determining whether candidate swine-specific fecal MST markers can be detected in environmental waters in NC, an area with high swine density, is important to assess whether these markers could be useful tools to evaluate and implement best management practices (BMPs).

In this study we aimed to evaluate the impact of swine CAFO liquid waste land application on the sanitary quality of proximal surface waters in NC. The study's specific objectives were to estimate concentrations of fecal indicator bacteria (fecal coliforms, *Escherichia coli*, and *Enterococcus*) in surface waters proximal to swine CAFO liquid waste land application spray fields and to field test candidate MST markers of swine fecal wastes in surface water samples proximal to swine CAFO liquid waste land application sites.

2. Methods

2.1. Study location

Sampling was conducted in the coastal plain region of eastern NC where there is a high density of swine, chicken, and turkey CAFOs as well as beef cattle on pasture. Swine CAFOs typically use liquid waste management systems (lagoons and spray fields), whereas most poultry CAFOs in the area use dry litter waste management systems in which waste-laden litter is applied to fields. Many rural homes in the area use septic systems for sewage disposal. Sampling locations were selected proximal upstream and proximal downstream of three swine CAFO liquid waste land application fields (Sites 1–3), where streams could be sampled from a public right-of-way. We use the letters A and B to denote proximal upstream and proximal downstream locations, respectively, at each swine CAFO surface water sampling site; however, "A"

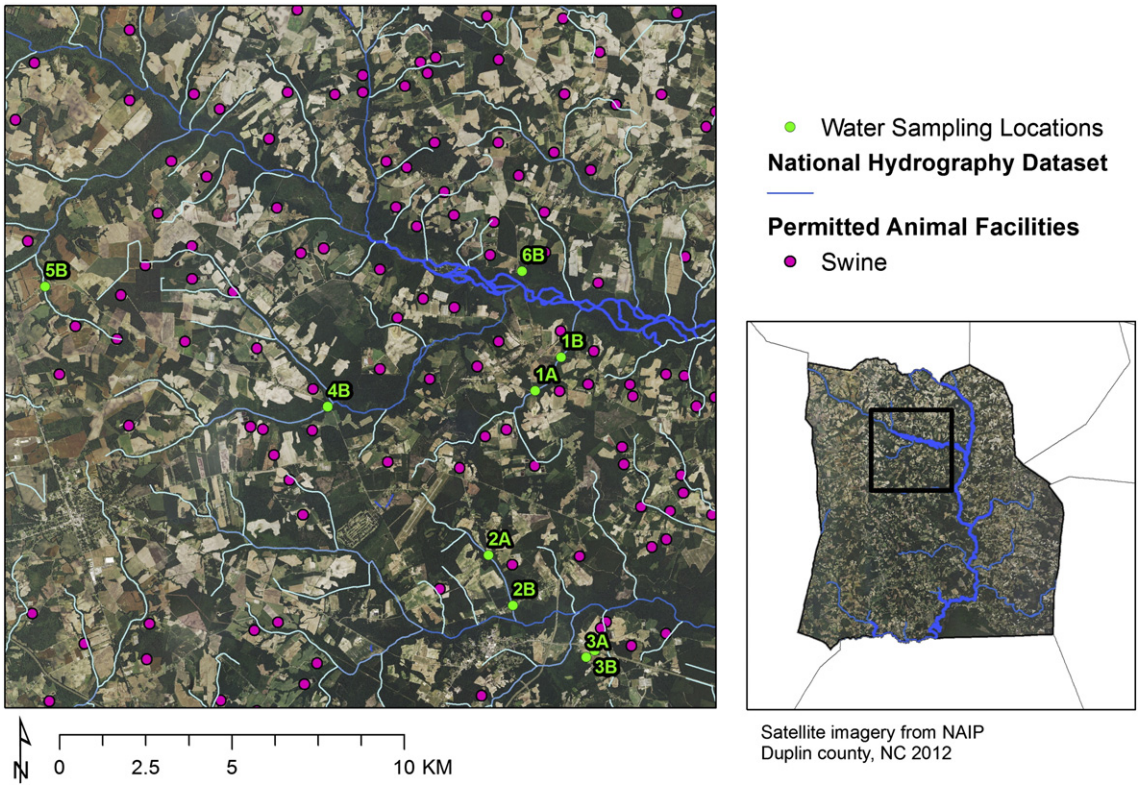

Fig. 1. Map of surface water sampling sites proximal to swine concentrated animal feeding operation spray fields, North Carolina.