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Short Communication

Aeration remediation of a polluted waterway increases near-surface coarse and culturable microbial aerosols

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HIGHLIGHTS

- Vertical gradient in culturable bacterial aerosols was detected above a polluted public waterway.
- Higher numbers of culturable bacterial aerosols were closer to the water surface.
- Likely sources for these bacterial aerosols include terrestrial and aquatic environments.
- Aeration of these polluted waters enhances the water–air bacterial connection.
- Aeration increased water–air transfer of bacteria in genera known to contain pathogens.

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ABSTRACT

Aeration remediation is currently used in polluted urban waterways to increase oxygen levels in the water column. Recent studies have provided increasing evidence that the bursting of bubbles at water surfaces introduced by aeration, or other surface disturbances, can transfer viable bacteria to the air. In heavily sewage-polluted waterways these water-originated bacterial aerosols may pose as a health risk to recreators in small boats or residents inhabiting the shoreline. Nonetheless, few studies have explored aerosols above active aeration remediation projects in waterways or investigated how bacterial aerosols change with vertical distance from aeration activities. This study, conducted at the Newtown Creek superfund site in Brooklyn, NY, USA, measured coarse aerosol particles and culturable bacteria in near-surface air above waters undergoing aeration remediation. Regardless of aeration operation culturable bacterial fallout was greater near-surface (0.6 m above water) than previously-reported measurements made at 2.5 m. Molecular analysis of the 16S rRNA gene sequences from isolated bacteria demonstrates that water and air shared a large number of bacterial genera and that the genera present in the near-surface aerosols (0.6 m) contained water-associated *Vibrio* and *Caulobacter*, which were not present at 2.5 m, despite the smaller sequence library size from the near-surface. Also, the near-surface microbial assemblage had significantly greater association with sequences detected previously in aquatic environments compared to the 2.5 m library. We found compelling evidence that aeration activity contributed to this vertical gradient in bacterial aerosol concentrations and identity. Similar to results from 2.5 m, concentrations of near-surface respirable coarse aerosols (<10 um) increased significantly when aeration was occurring. Culturable bacterial aerosol fallout was also greater near-surface when the aerator was on compared to simultaneous measurements made at 2.5 m. Furthermore, when the aerator was operating, the near-surface bacterial aerosol assemblage was statistically more similar to water assemblages than when the aerator was off. These findings highlight the potential for aeration remediation to increase exposure to viable bacterial aerosols in recreators (e.g. kayakers), a problem of greater concern where surface water is heavily polluted with sewage, as in Newtown Creek.

1. Introduction

In aquatic systems, aerosols can be formed from water surfaces through wind–wave interactions, wave–shore interactions, recreational water use, and aeration remediation of public waterways (Dueker et al., 2012a). This aerosolization process results in the transfer of aquatic surface materials, including bacteria, to the air(Blanchard, 1989). These aerosolized bacteria can be transferred in a viable state across the urban shoreline by onshore winds (Dueker et al., 2012a, 2012b, 2011). In most coastal urban centers, water quality is often compromised by the release of treated and untreated wastewater to estuarine and marine areas (Howarth et al., 2003) and wastewater inputs to rivers,

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estuaries and coastal waters have been increasing (Niemi et al., 2004). When untreated sewage is released into the surface waters of estuarine and coastal systems, this fresh water discharge can remain in a density-stratified surface layer, where surface disruptions release this material into the air (Aller et al., 2005). Previous studies confirm the transfer of viable sewage bacteria from water to air, including a 12× enrichment of sewage bacteria in coastal aerosols (Marks et al., 2001), increased inhalation contact with total coliforms during recreational activity in polluted coastal waters (Bradley and Hancock, 2003), and the presence of sewage-associated bacteria in air above Newtown Creek, an aquatic superfund site and tributary of the Hudson River Estuary (HRE) in Brooklyn, NY, USA (Dueker et al., 2012a).

Aeration remediation is currently being deployed in polluted urban waterways to increase oxygen levels in the water column (Burden et al., 2008). Recent studies provide building evidence that the bursting of bubbles at water surfaces introduced by aeration or other surface disturbances can transfer viable bacteria to the air. Nonetheless, few studies have explored the near-surface conditions in close proximity to active aeration remediation projects or investigated how microbial aerosols change with distance from the aeration activities. Because aeration remediation is conducted in highly polluted waters often containing sewage contamination, and because untreated sewage can contain numerous pathogenic bacteria (Korzeniewska et al., 2009; Tourlousse et al., 2008), high levels of endotoxins (Gangamma et al., 2011), and increased concentrations of antibiotic resistant bacteria (Young et al., 2013), it is important to better constrain the role of these remediation efforts in creating aerosols in the aquatic environment.

Presumably, closer proximity to aquatic sources of these aerosolized bacteria would result in a higher probability of exposure to them. Vertical gradients in microbial aerosol concentrations over terrestrial systems have been reported, with higher concentrations associated with closer proximity to ground-based sources (Khattab and Levetin, 2008; Lindemann et al., 1982). Vertical gradients in the aquatic environment have to date primarily been explored in relationship to wastewater treatment facilities (e.g. Goff et al., 1973), but not in public waterways. To bridge this scientific gap, we measured near-surface microbial aerosol deposition and coarse aerosol particles at heights relevant to small-craft boaters on a public urban waterway, Newtown Creek. Newtown Creek receives high levels of industrial waste, raw sewage release through combined sewer outfalls (CSOs), and oil seepage (Apicella et al., 1996), and was designated as an EPA superfund site in July 2011 (Mugdan, 2011). We sampled in the English Kills portion which is currently undergoing aeration remediation through a city-sponsored pilot project and where recreational boaters are known to paddle (Burden et al., 2008).

Whereas prior measurements taken at 2.5 m above the English Kills water surface detected increases in coarse aerosol particle concentrations at this site when aerators were on, there was no significant difference in culturable bacterial fallout detected at this height (Dueker et al., 2012a). Since small-boaters, who are commonly observed on this waterway, like kayakers, canoeists and rowboaters are much closer to water surfaces (<1 m), they may be in closer contact with contamination emitted by aeration in polluted waters that would not be detected at 2.5 m. To test this hypothesis, we conducted near-surface sampling of coarse and bacterial aerosols at this site when aerators were on and when they were off (measurements made simultaneously with the 2.5 m measurements reported in Dueker et al. (2012a)). If proximity to polluted water increased exposure to water-originated aerosols, we expected to find increased near-surface microbial aerosol fallout and increased influence from aquatic surfaces compared to previously reported measurements taken at 2.5 m (Dueker et al., 2012a). Also, if aeration remediation was a primary production mechanism for near-surface microbial aerosols, we expected to see an increase in near-surface coarse aerosols and microbial fallout when the aerator was on compared to when the aerator was off, and an increased aquatic contribution to those aerosols.

2. Material and methods

Sampling was conducted in the English Kills portion of Newtown Creek, Queens, NY, USA (40.711731 N, 73.931431 W) under onshore wind conditions. As per Dueker et al. (2012a), sampling was conducted only under no wind or very low (<3 m s^{-1}) wind speed conditions, and under a restricted range of environmental conditions. Viable bacterial aerosols are thought to increase with relative humidity (Hatch and Dimmick, 1966) while decreasing under high solar radiation conditions (Tong and Lighthart, 1997) and following rainfall due to scavenging of particles by precipitation (Lewis and Schwartz, 2004). To control for these environmental factors, simultaneous (paired) measurements were compared at the two sampling heights, minimizing the effects of these environmental parameters across sampling events. Samples were collected over the course of 5 full sampling days in the fall of 2010 (3 days with the aerator on, 2 days with the aerator off), simultaneously with 2.5 m aerosol measurements made by Dueker et al. (2012a). To gain a comprehensive understanding of the aerosols a small-boater could encounter when paddling on English Kills, coarse and bacterial aerosol samples were collected from a stationary metal rowboat deployed at five sites along a transect spanning the width of the creek (Fig. 1).

2.1. Vertical gradient

Near-surface culturable bacterial fallout was measured at transect sites by exposing triplicate agar plates of two separate media types (R2A and Luria–Bertani (LB)) for 15 min to ambient aerosols from a wire platform positioned at 0.6 m above the water surface, upwind of the stationary rowboat and particle profiler. In previous studies, both LB and R2A media have been successfully used to grow diverse bacterial assemblages from aerosols and water from brackish environments (Lighthart and Shaffer, 1995; Shaffer and Lighthart, 1997). The use of growth media plate exposures, in contrast to culture-independent approaches, ensured that the microbes enumerated and characterized using molecular genetic approaches were viable and therefore had the potential to contribute to infective load. This approach resulted in a useful measure of relative bacterial viability (Dueker et al., 2011, 2012a, 2012b; Cho and Hwang, 2011; Urbano et al., 2011), although it underestimates the total numbers of viable bacteria depositing since not all viable bacteria are culturable.

After exposure in the field, plates were incubated in the laboratory for 5 days at 25 °C (room temperature) in the dark, after which bacterial colony forming units (CFUs) were counted. Microbial aerosol fallout rate (CFU m^{-2} s^{-1}) was calculated using the surface area of the exposed Petri dishes (0.0079 m^2) and the duration of exposure. To assess for

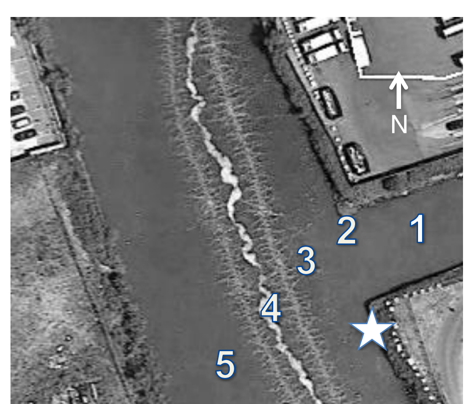

Fig. 1. English Kills portion of Newtown Creek, Brooklyn, NY, USA (Google Earth image 8/2/13), with five near-surface sampling sites superimposed. Whitewater indicates aeration operation. White star designates mooring site of R/V R. Ian Fletcher (Riverkeeper).