The effect of two mechanical beach grooming strategies on *Escherichia coli* density in beach sand at a southwestern Lake Michigan beach

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The influence of indicator bacteria associated with beach sands on recreational water quality has become increasingly recognized. Constant wave action may serve as a transport mechanism for delivering bacterial organisms to surface waters resulting in an increased frequency of dry weather advisories. The ability to reduce the concentration of these organisms may serve to improve recreational water quality. To date, few researchers have explored anthropogenic factors affecting the content of Escherichia coli *in beach sands. This study explored the influence of mechanical beach grooming on in situ populations of* Escherichia coli *at a southwestern Lake Michigan beach to determine if an alteration in current beach management practices would serve to reduce the number of dry weather advisories in this community. Preliminary studies conducted during 2001 demonstrated that professional grooming significantly increased* Escherichia coli *content in beach sands relative to non-groomed or hand raked plots ($p < 0.001$). This data also suggested that deeper grooming might reduce differences between groomed and non-groomed areas. Subsequently, two mechanical grooming techniques were compared at Racine, WI in 2002: groomed to a depth of 5 to 7 cm with leveling of beach sands and groomed to a depth of 7 to 10 cm without leveling.* Escherichia coli *content between treatments were significantly correlated ($p < 0.009$). The density of the bacterium in deeper groomed/unleveled sands was significantly lower in visibly moist or wet but not dry sands ($p = 0.038$). In 2003, the manner in which beach sands were maintained using the mechanical beach groomer was altered and a follow-up study conducted. A 30 percent reduction in the number of poor water quality advisories due to dry weather events was achieved as a result of these measures. These results demonstrate that mechanical beach grooming may affect* Escherichia coli *content in beach sands, a potential source of non-point pollution to recreational waters.*

Keywords: Great Lakes, indicator bacteria, non-point pollution, recreational water quality, sediment

Introduction

Fecal contamination of recreational water can occur from a variety of point and non-point sources (Calderon et al., 1991; Bartram and Rees, 2000; Solo-Gabriele et al., 2000). Although raw sewage (De Paepe et al., 2001; USEPA, 2002) and sanitary/storm water discharge associated with rainfall events (McLellan et al., 2001; USEPA, 2002) are often considered primary sources of contamination, inputs of non-point origin may impact surface water quality significantly (Wyer et al., 1997). Overt sources of contamination may mask less obvious contributors such as those of non-point origin. Non-point sources of contamination

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are difficult to assess and yet may be responsible for frequent poor recreational water quality advisories, especially those attributed to dry weather events where the source of contamination becomes more difficult to pinpoint. A sanitary survey including an assessment of non-sewage, non-outfall, contributors of fecal contamination is necessary in order to determine appropriate remediation steps for the improvement of near shore water quality (Wyer et al., 1997).

Beach sands have become increasingly recognized worldwide as sources of non-point contamination for their ability to harbor bacteriological indicators and influence recreational water quality (Whitman and Nevers, 2003). This effect may be enhanced where a ready nutrient source such as algae is available (Grant et al., 2001; Desmarais et al., 2002; Byappanahalli et al., 2003). Some researchers suggest that they be monitored in conjunction with surface waters during the swimming season (Olańczuk-Neyman and Jankowska, 2001) indicating that they may pose a health risk themselves to certain populations of beach goers (Rusin et al., 1997; Bonadonna et al., 2002). In a recent study performed at the 63rd Street Beach, Chicago, Illinois, newly placed upland sands were monitored for *Escherichia coli* density. Over the course of two weeks the density of *E. coli* in foreshore and backshore sands and near shore waters increased dramatically suggesting that the while new sands temporarily decreased *E. coli* content they eventually became a reservoir for this organism (Whitman and Nevers, 2003).

In Racine, WI water quality advisories neither are consistently associated with identifiable sources of pollution nor significantly correlated to rainfall events (Kinzelman et al., in press). The large resident population of seagulls (often numbering up to 1000 individuals per day) and near shore beach sands have frequently been hypothesized as significant non-point sources of pollution possessing the capability to impact adjacent surface waters in the absence of rainfall. Fecal droppings from birds may account for a significant contribution of indicator organisms, including *E. coli*, to sediment including intertidal zones (Grant et al., 2001; Oshiro and Fujioka, 1995; Jones and Obiri-Danso, 1999; Obiri-Danso and Jones, 2000) and foreshore sands (Whitman et al., 2001). Whitman and Nevers (2003) Chicago study indicated a significant correlation exists between the density of *E. coli* in beach sands and the presence of seagulls. Researchers in Huntington Beach, California hypothesize that a large reservoir of indicator bacteria in foreshore and near shore sediments may be continuously washed into the surf zone by wave action (Boehm et al., 2002). In Racine, a significant correlation was determined between surface water, *E. coli* concentration and wave height indicating that a viable mechanism for the transport of indicator organisms from beach sands to recreational waters exists at this study site (Kinzelman et al., in press). Therefore, fecal loading of the sand in the absence of adequate remediation and under favorable environmental conditions could be partially responsible for high numbers of *E. coli* recovered from recreational waters (Standridge et al., 1979; Davies et al., 1995).

Mechanical manipulation of beach sands for the removal of debris is a common practice throughout the world. Removal of visible wastes improves the aesthetic value of the beach while providing protection to the health of the public through the removal of hazardous materials. Benefits such as these are obvious. Although researchers have shown a relationship between surface sediments and higher concentrations of *E. coli* (Desmarais et al., 2002), little attention has been given to the effects of natural and anthropogenic measures (such as mechanical manipulation) on poor recreational water quality, defined as the presence of high densities of fecal indicator organisms such as *E. coli*. The manner in which beach sands are manipulated may serve to increase the bacterial burden on adjacent surface waters. Further evaluation of daily foreshore beach grooming is required to determine to what extent such processes can be altered to minimize *E. coli* contamination of sand and prevent its transportation to bathing waters, thereby reducing non-point pollution from this source. The purpose of this research was to evaluate the actual effect of two mechanical beach grooming techniques on *E. coli* density in beach sands at North Beach, Racine, WI. The determination of whether or not grooming at greater depths relative to the current grooming practice is effective in reducing *E. coli* concentration in beach sand which will result in the development of targeted beach management strategies to reduce the bacterial burden on adjacent surface waters.

Materials and methods

Background

Daily professional grooming of North Beach is a practice that has been in place for more than twenty-five years, currently accomplished using the Barber^{TM} Surf Rake Mechanical Beach Groomer (Model 600 HD, Naugatuck, CT). Large solids are removed from beach

sands by the spring tines that carry the debris initially onto a conveyor and subsequently into a hopper for later disposal. A 100-kg serrated finisher trails behind the groomer and serves to level and smooth the beach.

To determine whether mechanical grooming depth or grooming frequency had a significant effect on the amount of *E. coli* recovered from beach sand at North Beach in Racine, WI, a preliminary, controlled experiment was performed for two weeks in 2001. In this study, varied depths of grooming were achieved by hand raking with a thatching rake. The relationship of beach grooming on *E. coli* concentrations in the 2001 study indicated that certain mechanical manipulations of beach sand might have the adverse effect of increasing or promoting bacterial persistence. This effect was most pronounced after a heavy rainfall that may have acted to enhance bacterial persistence although conclusive evidence could not be drawn due to the limited duration of the study (Kinzelman et al., 2003).

Study site

Racine, Wisconsin is approximately 130 km north of Chicago, Illinois and 50 km south of Milwaukee, Wisconsin on the southwestern shore of Lake Michigan. Recreational water quality is determined using an *E. coli* standard (USEPA, 1986; APHA, 1998) based on previously documented studies demonstrating its relationship to swimming-associated illnesses (e.g., gastroenteritis and diarrhea; Dufour, 1984; USEPA, 1986, 2000).

Water samples are routinely collected at four equidistant sites along the 1 km designated swimming area of North Beach during the summer. Randomization of treatment areas for this study were based on the fact that initial studies indicated that there was no significant difference in *E. coli* densities at the four regulatory sites and, therefore, the potential influence from non-point pollution over the length of the beach would be similar.

Sample collection

The true depth of mechanical grooming is the actual depth that the tines are capable of penetrating the sand as limited by their physical length. The actual depth of grooming is not readily measurable in the field due to the nature and consistency of the sand and, therefore, in evaluating treatments, the effective depth was used. For the purpose of this study, the effective depth was defined as the depth of the furrow left in the sand as a result of the treatment. The effective depth was measured daily using a metric ruler (cm) inserted into a representative portion of the furrow for each treatment. Consultation with the manufacturers of the Surf Rake® and experimentation with the equipment itself allowed for adjustments in the machine settings such that the actual depth of penetration consistently provided an effective depth mimicking that previously demonstrated by deep hand raking (3–4 cm). In order to achieve the deeper depth, the groomer was set to the maximum depth of raking and the finisher was omitted. For the purpose of this study, the two treatments would then consistent of daily status quo grooming and deeper grooming. Both treatments were performed each morning prior to sand sample collection.

Sand samples were collected with an AMS soil recovery probe (Art's Manufacturing and Supply, American Falls, ID) with a 2.8 cm bore and sterilized butyrate liners. Twelve random samples were taken in the same manner from both the 'status quo' and deeper groomed areas each day for 20 days ($n = 240$ samples per treatment). Each sampling area was approximately 30 m × 50 m, located within the designated swimming area, and abutted one another. All samples were obtained between 6:30–8:00 AM, returned to the laboratory on ice packs, and analyzed within one hour of collection.

Field conditions including number of seagulls, sand condition, and wave height were noted daily. Seagulls were counted twice daily (morning and afternoon) and weekly averages were determined based on daily counts. Sand condition (wet, damp or mixed, dry), for the purpose of this study, refers to moisture content as determined by a visual inspection of the sand prior to collecting sand core samples each day. A designation of wet indicates that the beach sand was visibly and uniformly wet, damp or mixed indicated that there was patchy moisture visible on the surface of the beach sand to varying degrees, and dry indicates that the beach sand was visibly and uniformly dry in appearance. Wave heights were estimated as being low (calm), medium (<0.5 m), or high (>0.5 m).

Laboratory analysis

At the laboratory, core samples were weighed, and the contents of each butyrate liner were emptied into a sterile vessel. The average core length was 10.0 cm. Sand samples were eluted for 30 seconds by vigorous hand shaking in a phosphate buffered water mixture ($pH = 7.2 \pm 0.2$) and were then serially diluted after one minute without disturbance. Concentration of *E. coli* in each sample was determined by the membrane filtration

technique using m TEC agar (APHA, 1998). *E. coli* colonies were confirmed by the substrate test (negative urease activity). Daily quality control was performed using a positive control (*E. coli* ATC #25922) and sterility was ensured at all steps. Bacterial densities in the sand samples were calculated and expressed per gram dry weight of sample (wet/dry conversion factor = 0.833). Statistical analyses of treatment main effects were done by repeated measures ANOVA on log-transformed data. Paired t-test and repeated measures ANOVA were used to test contrasting treatments when appropriate.

Results

2002 grooming study

In 2002, two grooming techniques were compared at Racine: groomed to a depth of 5 to 7 cm with leveling (status quo) and groomed to a depth of 7 to 10 cm without leveling (deep grooming). The effective depth of grooming remained constant for both treatments during the course of this study when the beach sand conditions were recorded as dry (Table 1). When the beach sand conditions were recorded as either damp/mixed or wet the area maintained without the finisher had a greater effective depth of grooming (Range = 0–4.5 cm) than the area maintained with the finisher (Range = 0–0.9 cm) (Table 1). Omitting the finisher also resulted in beach sand with a more aerated rather than compacted appearance. The *E. coli* content between the two treatments was correlated ($p = 0.009$) indicating that a valid comparison between the two treatments could be made.

Table 1. Mean depths and ranges, in centimeters, for two grooming treatments using the SurfRake® mechanical beach groomer, with and without the finisher.

Variation in Depth of Grooming by Sand Condition			
	Mean Effective Depth of Grooming (cm)		
	Sand Condition		
Treatment Type	Wet	Damp/Mixed	Dry
Without finisher	2.4	1.4	0.2
Range	2.0–4.5	0–3.0	0–0.5
With finisher	0.4	0.6	0.2
Range	0–0.9	0.5–0.75	0–0.5

Two data sets were determined based on treatment type, each consisting of the mean daily *E. coli* concentration in CFU g^{-1} ($n = 12$ samples per treatment per day), for a total of 20 data points per treatment. These data sets were further subdivided based on sand condition (wet/damp or mixed and dry). Upon examining the 'dry' subset, there was no significant difference between the density of *E. coli* recovered from either of the treatments. An independent group t-test performed on the 'wet/damp or mixed' data subset indicated a significant difference in the mean concentration of *E. coli* between the treatments ($p = 0.018$). Additionally, when the sand condition was recorded as visibly moist or wet the area groomed deeper and without the finisher yielded core samples containing significantly fewer *E. coli* g^{-1} than the area maintained at a shallower depth and employing the finisher ($p = 0.038$) (Figure 1).

The number of gulls recorded during the course of this study remained high (an average weekly range of 470 to 636 individual birds based on tabulated twice-daily counts) (Table 2). Wave height was variable and height did not always correlate with adverse weather conditions or rainfall. Of the 13 days that the sand condition was designated as wet or damp/mixed only 5 were associated with precipitation in the 24-h period preceding sample collection (Table 3).

2003 validation study

To validate the hypothesis that the manner in which beach sands were maintained could impact non-point source contributions, beach management practices were altered beginning in May 2003. From that date forward, grooming occurred at the maximum depth achievable with the equipment, omitting the finishing step that had previously leveled beach sands. The occurrence of advisory events and incidence of rainfall was tabulated and compared to similar data from 2002. The number of advisories attributed to the occurrence of precipitation (point source) within the 24-h period preceding collection of the sample increased from 9 out of 20 (45%) in 2002 to 14 out of 24 (58%) in 2003. The frequency of dry weather events (non-point source) decreased by 30% (Table 4).

Discussion

The initial action of the beach groomer's tines is very dispersive while the following finisher compacts and levels the beach sand. When sand conditions were dry there was no visible difference between grooming deeper and omitting the finisher and the current

Table 2. Mean number and range of seagulls observed at North Beach during the course of the 2002 beach grooming study.

Number of Seagulls at North Beach, Racine, WI, July 2002				
Week Beginning With	Mean # Seagulls, AM	Range, AM	Mean # Seagulls, PM	Range, PM
July 8	615	370–1030	604	81–1150
July 15	629	467–1001	311	46–670
July 22	675	336–1050	596	320–760
July 29	696	544–975	273	14–720

grooming method. The dry sand fell in on itself regardless of how it was maintained and the beach presented a rather uniform appearance regardless of the treatment type. When the sand condition was damp/mixed or wet the difference between the grooming treatments was very visible. Increasing the depth of grooming and omitting the finisher yielded aerated sand with a deep furrowed appearance while the status quo grooming treatment presented sand that was rather level and compacted. The altered appearance of the deeply groomed beach during wet conditions may be the key as to why variation in grooming techniques is able to alter bacterial density in sand. Empirically, the more aerated sand would dry more rapidly when wet and at the same time allow for deeper ultra-violet (UV) light penetration by the sun than the more compacted sand. Bacteria originating from fecal material on the surface of the sand could be provided with a more hospitable environment for persistence or growth in compacted sands when conditions are warm, moist and protected from UV light. Aerated sands, allowing for more rapid desiccation and light penetration, may have the effect of promoting more rapid die off of microorganisms accumulated on beach sands.

Table 3. Variation in sand condition (wet, damp/mixed, dry) based on wave height (low = calm, moderate <0.5 m, high > 0.5 m) and precipitation (2002).

Date	Sand Condition	Wave Height	Precipitation (Inches)
7-8-02	Dry	Low	0.0
7-9-02	Wet	High	1.38
7-10-02	Wet	High	0.02
7-11-02	Wet	High	0.0
7-12-02	Damp	Moderate	0.0
7-15-02	Dry	Low	0.0
7-16-02	Dry	Low	0.0
7-17-02	Dry	Low	0.0
7-18-02	Dry	Moderate	0.0
7-19-02	Wet	High	0.0
7-22-02	Damp	Moderate	0.0
7-23-02	Wet	High	0.0
7-24-02	Wet	High	0.0
7-25-02	Wet	High	0.0
7-26-02	Wet	Moderate	2.21
7-29-02	Wet/dry	Moderate	0.12
7-30-02	Dry/wet	Moderate	0.0
7-31-02	Dry	Low	0.0
8-1-02	Dry	Moderate	0.0
8-2-02	Wet	Wet	0.05

Gull and other wildlife droppings were visible on beach sands throughout the course of this study. The mean number of gulls recorded in the morning for each week of the study was consistently higher than the afternoon average indicating that these birds may tend to roost on beach sands at night. On average, 1-gram of seagull feces contains 340 million *E. coli* bacteria (Sandra McLellan, Univ. of Wisconsin—Milwaukee, WATER Inst., pers. comm.). If the average number of seagulls observed at a single point during the course of study were to deposit only one gram of feces on beach sands it would translate into a fecal burden of 93–240 billion *E. coli*. Considering this fact, the actual fecal mass deposited by the number of seagulls

Table 4. Comparison of dry weather and rainfall associated advisory events prior to (2002) and after (2003) altering mechanical beach grooming techniques at Racine, WI.

	2002	2003
Total # events	20	24
Dry events	11 out of 20	6 out of 24
% of total	55%	25%
Rainfall events	9 out of 20	14 out of 24
% of total	45%	58%
Other events	0 out of 20	4 out of 24
% of total	0%	17%

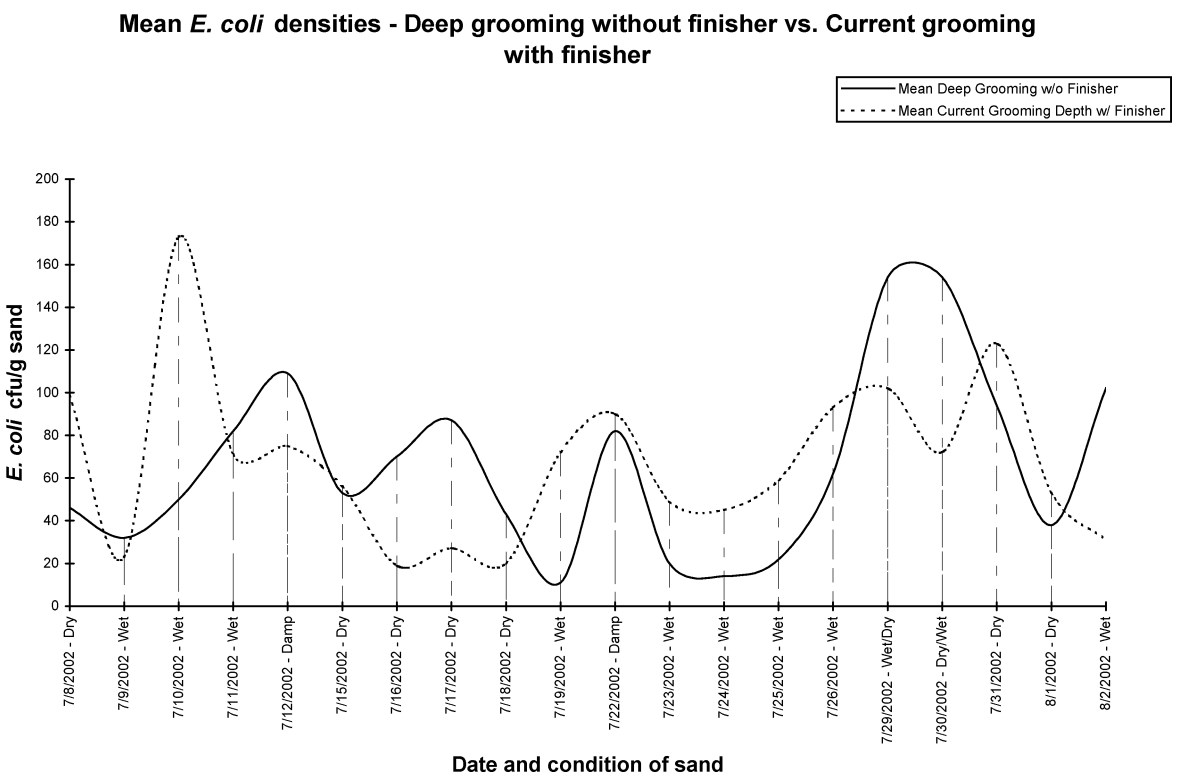

Figure 1. Variation in *E. coli* concentration (CFU g^{-1} dry sand) based on sand condition.

observed in this study, in a nutrient rich environment, could provide a high enough *E. coli* burden to impact adjacent receiving waters negatively. Previous modeling at North Beach using multivariate analysis indicated a significant relationship between current surface water *E. coli* counts and the previous days *E. coli* counts in conjunction with wave height ($p = 0.02$) (Kinzelman et al., in press). It is feasible then that high waves repeatedly washing over the berm crest to the nearshore area of the beach sand could transport bacterial organisms from onshore sediment to surface waters as they recede.

Conclusion

Manipulation of sands by means of mechanical grooming equipment creates an aesthetically pleasing appearance for beach patrons in addition to removing potentially hazardous debris such as broken glass and animal waste. While performing an important health function by protecting the public, the process of beach grooming needs to be re-examined with regard to its effect on the accumulation of bacterial indicators and subsequent transport of these microorganisms to bathing waters. Beach sand, subjected to a variety of environmental challenges, may be significant a contributor of non-point source pollution to adjacent surface waters. In the case of North Beach, significant populations of seagulls appeared to contribute over time to the accumulation and possible persistence of the indicator organism *E. coli* in the sand.

In this study, mechanical beach grooming techniques were assessed for their ability to influence bacterial content in these sediments. This research demonstrated that the status quo grooming technique, employed for the past 25 years, selectively promoted the persistence and/or regrowth of *E. coli* based on sand condition (presence or absence of moisture). Conversely, altering the way in which these sediments were maintained could influence bacterial density. Increasing the depth of grooming and omitting the finisher when the sand condition was noted as damp/mixed or wet provided an effective means of reducing the concentration of *E. coli*, ultimately providing a 30% reduction in the number of non-point source associated (dry weather) advisories at the study site.

Questions regarding the identification and remediation of point and non-point contamination sources and their relative contribution to poor recreational water quality are continually being addressed. Non-point sources of pollution are often difficult to detect and correct and an assessment of bathing water quality may necessitate the inclusion of individuals across various disciplines for the determination of the sanitary quality and potential public health risks (Efstratiou, 2001). In Racine, a cooperative effort between laboratory personnel and public works employees reduced non-point source contamination from near shore sands. An examination of current beach management practices, including mechanical grooming techniques, may serve to reduce non-point pollution and lead to a reduction in the number of poor water quality advisories posted annually at other Lake Michigan or Great Lakes bathing beaches.

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