Maine Healthy Beaches Program
Oceanographic and Meteorological Study

Microbial Pollution Levels and Transport Pathways at Ogunquit Beach

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in cooperation with

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INTRODUCTION

The purpose of this report is to research potential relationships between high levels of *Enterococci spp.* bacteria data collected by the Maine Healthy Beaches Program (MHBP) for Ogunquit Beach and hydrodynamic and meteorological conditions that may influence recorded bacteria levels. This report supplements a previous study completed by the Maine Geological Survey (MGS, Slovinsky and Dickson, 2008) of the ebbing tidal currents in the vicinity of the Ogunquit River.

Maine Healthy Beaches Program Data

The Maine Healthy Beaches Program has been monitoring *Enterococci* levels at four locations at Ogunquit Beach: OG-1, at the Ogunquit/Moody Beach border; OG-2, at the footbridge along Ogunquit Beach; OG-3, at the Norseman Motor Inn along Ogunquit Beach; OG-4, at the western edge of the parking lot, in the Ogunquit River. Starting in the 2006 sampling season, a fifth location (OG-5) was added at the pocket beach seaward of the Ogunquit River called Little Beach. The sample locations are shown in Figure 1. Samples were typically collected once a week during the summer months (i.e., Memorial Day through Labor Day), and recorded *Enterococci* levels (colonies/100mL), the time of sampling, salinity (parts per thousand, ppt), air and water temperature (ºC), tidal stage, and site observations. Information relating to the available sampling dataset is shown in Table 1.

Site	2003	2004	2005	2006	2007	Totals
OG1	14	14	15	15	18	76
OG2	13	15	15	15	20	78
OG3	14	16	15	17	23	85
OG4	15	15	19	20	26	95
OG5	0	0	0	12	23	35

Table 1. Number of collected water quality samples for each site (Maine Healthy Beaches Program).

Supplemental Hydrodynamic and Meteorological Data

The Maine Geological Survey (MGS) was able to acquire additional hydrodynamic and meteorological data that corresponded with the periods of data collection. We focused on 2004-2007 since no samples exceeded required *Enterococci* levels in 2003 (see Table 2). Hydrodynamic data were available from the Gulf of Maine Ocean Observing System Buoy B (Western Maine Shelf; GoMOOS, 2008). This included hourly significant wave height, wind speed and direction, daily precipitation, and hourly tidal data. For ease in comparison with the daily sampling protocol, significant wave height, wind speed and direction, and hourly tidal data (i.e., averaged high and averaged low) were averaged for each 24 hour period. Daily meteorological conditions, including precipitation data for the Portland International Jetport, were available from the National Oceanic and Atmospheric Administration’s National Climatic Data Center (NCDC, 2008).

RESULTS

Initial Data Analysis

Analysis of collected data from the MHBP shows that 369 total samples were collected at OG-1 through OG-5, from 2003 to 2007 (2006-2007 for OG-5). Of these, 37 samples showed bacteria levels that exceeded threshold level of 104 col/100mL. All samples taken in 2003 and 2004 were generally clean, while more samples exceeded levels in 2005 through 2007 (Table 2). OG-1 and OG-2 were generally the lowest scoring samples, while OG-4, located on the western side of the parking lot at the southern end of the beach, accounted for the most number of high samples. Between 20-30% of the samples taken at OG-4 exceeded recommended bacteria levels during sampling from 2005 through 2007.

	2003			2004			2005			2006			2007			2003-2007 Totals			
Site	N	N>104 col	%	N	N>104 col	%	N	N>104 col	%	N	N>104 col	%	N	N>104 col	%	**Site**	N	N>104 col	%
OG1	14	0	0.0	14	0	0.0	15	1	6.7	15	1	6.7	18	0	0.0	**OG1**	76	2	2.6
OG2	13	0	0.0	15	1	6.7	15	1	6.7	15	1	6.7	20	3	15.0	**OG2**	78	6	7.7
OG3	14	0	0.0	16	1	6.3	15	2	13.3	17	3	17.6	23	2	8.7	**OG3**	85	8	9.4
OG4	15	0	0.0	15	1	6.7	19	4	21.1	20	6	30.0	26	5	19.2	**OG4**	95	16	16.8
OG5	0	0	0.0	0.0	0	0.0	0	0	0.0	12	2	16.7	23	3	13.0	**OG5**	35	5	14.3

Table 2. Collected sample data, including exceedences, for OG-1 to OG-5 collected from 2003 through 2007 (Maine Healthy Beaches Program).

Results from the current study by MGS (Slovinsky and Dickson, 2008) showed that ebbing currents from the Ogunquit River likely traveled northward, along the beach for some distance. If it is assumed that the river was the source of pollution (as a null hypothesis), one would expect to see a general pattern that reflected the highest bacteria levels within the river, and lower levels from OG-3 through OG-1. The primary reason for lower levels away from the river mouth is that river water will mix with more and more seawater as it travels north along the beach in the nearshore and surf zone. The hypothesis we developed is to test whether or not the bacteria levels decrease from south to north along Ogunquit Beach.

To investigate this hypothesis, we looked at the gradient of sample scores for OG-4 to OG-1. Samples were taken at OG-1 to OG-4 a total of 62 days. Of these, 19 days occurred where at least one sample exceeded 104 col/100mL. Within those days, there was a noted south-to-north gradient in bacteria levels on 15 days. So on 79% of the dates with at least one sample with a high bacteria level there was a south-north gradient. ***The spatial pattern of high bacterial samples supports the hypothesis that the Ogunquit River is the source of bacterial pollution along Ogunquit Beach***.

Initial Data Relationships

This section describes the potential relationships between the recorded bacteria levels and other data collected by volunteers as part of the Maine Healthy Beaches Program. Notably, salinity and water temperature are investigated.

Salinity. Since our working hypothesis is that the Ogunquit River is the source of bacteria on the beach, we would assume that lower salinity levels would relate to higher bacteria counts. Since the ocean salinity is approximately constant, a lower salinity indicates fresh water has mixed with ocean water. In this region, the primary source of fresh water capable of diluting salty seawater is the Ogunquit River. Figure 2 shows the relationship between *Enterococci* and recorded salinity for all sample locations. It is especially noted at the Ogunquit River site (OG-4) that, in general, the higher bacteria levels were recorded at lower salinity levels, indicating dilution by fresh water. This is also the case for OG-3, and OG-2 in a lesser sense. OG-1, which is quite far from the Ogunquit River mouth, does not appear to be influenced by this trend. ***The salinity data independently confirm that the source of pollution is water from the Ogunquit River***.

Water Temperature. Our summer study of currents on July 12, 2007 (Slovinsky and Dickson, 2008) identified a "cool" water mass that seemed to relate to freshwater exiting the Ogunquit river mouth, and traveling northward along the beach during an ebbing tide. The temperatures associated with this distinct mass were between 14-15ºC, while other temperatures within the study area were 15ºC and greater.

Temperatures collected at the time of water quality sampling show a huge seasonal range, from below 5ºC up to 20ºC (Figure 3). Water temperatures for OG-4 where bacteria levels were highest were between 15-16ºC, although there were many samples with bacteria levels above the 104 col/100mL limit where temperatures were between 17-19ºC. Six of the highest bacteria levels at OG-4 corresponded with temperatures between 15º and 16ºC; this cluster may be a signature of the cooler freshwater water mass of the Ogunquit River but the aggregated temperature data alone is not definitive of a river source due to seasonality in measurement dates.

For OG-3, the highest bacteria levels corresponded to a wide temperature range between 11-15ºC. Some of the low temperatures are due to the fact that samples are taken in May and June when seawater is coldest. At OG-2, the higher scoring samples corresponded with temperatures in an equivalent but slightly cooler range between 10-14ºC.

Overall, the temperature data show that high bacteria levels can be encountered at a wide range of water temperatures from 10-19ºC. ***Water temperature alone***

cannot be used to predict water quality will be either above or below the 104 col/100mL threshold.

Additional Data Relationships

MGS next investigated the relationships between bacteria levels and oceanographic and meteorological conditions, such as tidal elevation and precipitation. Several physical variables and their relationship to bacterial levels are examined below.

Tidal Range. In our 2005 study at Goose Rocks Beach in Kennebunkport, we found that tidal range in excess of 10 feet was important predictor of high bacterial levels (Slovinsky and Dickson, 2005). In that study, we found that "spring tides" or those with a higher range around the time of a full or new moon led to higher bacterial levels at the beach. Analysis of tidal range and elevations at southern California beaches determined that *Enterococci* levels increased during spring tides, and particularly during the ebb cycle (Boehm and Weisberg, 2005).

To examine the influence of tidal range on bacterial levels at Ogunquit Beach, we collected tidal data from the National Ocean Service. For each day that water quality data was collected, we averaged the low and high tide elevations to determine an average daily low and high tide elevation (referenced to Mean Lower Low Water, MLLW). Since the tides have a diurnal inequality (e.g. the two highs are not to the same elevation) an average represents a simple proxy for the volume of water flowing into and out of the estuary of the Ogunquit River. Furthermore, on dates with a large range, tides will rise higher into the salt marshes and perhaps reach into the freshwater fringing marsh environment. Also on dates with large tides, currents - and hence mixing - through the river mouth will be stronger due to the larger volume of water exchanged with the estuary (Lincoln and FitzGerald, 1988).

We also combined the average high and average low values to determine a daily tidal range. There appears to be a bimodal distribution of higher bacteria levels that correlate with a mean daily tidal range of 9.5 feet and also 10.5 feet, with the majority of exceedence values occurring just above the 9.5 feet range (see Figure 4). However, over 40% of all tidal range values are in the 9.5 to 9.65 foot range, indicating that high bacterial values centered around 9.5 feet may simply relate to the dominant (most common) tidal range. Unlike Kennebunkport, there is no strong concentration of high bacterial levels above the 10-foot range that suggests a marsh inundation influence. At this point, the significance of this bimodal distribution is not understood. Used as an independent variable, ***tidal range is not a predictor of high bacterial levels***.

Tidal Stage. We next analyzed the bacteria levels for each location in the context of recorded tidal stage. Of the 369 total readings taken from 2003-2007, 50% occurred on a flooding tide, and 50% occurred on an ebbing tide (Table 3). Of these, about 21% were taken during a mid-flooding tide, and 25% taken on a mid-ebbing tide.

Interestingly, the data shows that the majority of high scoring samples were collected during a flooding (low to high) tide, notably at the OG-3 and OG-4 locations. Of the 185 total incoming tide samples taken, 27 samples exceeded the recommended *Enterococci* level (roughly 16%), as opposed to only 7 samples (4%) on outgoing tides. This is counterintuitive, since the source of pollution – inferred from our current study (Slovinsky and Dickson, 2008) and from analyses presented above - is assumed to be the Ogunquit River. One would expect to see the majority of the higher bacteria samples to be recorded on an ebbing (falling) tide, especially at the river sample location of OG-4. With an even distribution of samples taken at OG-4 (i.e., flooding vs. ebbing), this anomaly suggests to us that ***OG-4 may not be in a location that catches potentially contaminated water on the ebbing tide***.

	OG1		OG2		OG3		OG4		OG5		Total Values			
Tidal Stage	N	# > 104	N	# > 104	N	# > 104	N	# > 104	N	# > 104	N (Total)	% Tides	>104 Total	% Exceed
L	7	0	4	0	11	**4**	11	**3**	4	0	37	10.0	7	18.9
LF	9	**1**	7	**3**	9	0	9	**5**	4	0	38	10.3	9	23.7
MF	18	0	18	0	19	**3**	15	**7**	7	**2**	77	20.9	12	15.6
HF	8	0	7	**1**	6	0	9	0	3	0	33	8.9	1	3.0
H	5	0	9	0	6	0	9	0	1	0	30	8.1	0	0.0
HE	7	0	7	0	6	0	7	0	3	0	30	8.1	0	0.0
ME	19	**1**	16	**1**	23	0	27	0	7	0	92	24.9	2	2.2
LE	3	0	11	**1**	5	0	7	**1**	6	**3**	32	8.7	5	15.6

Table 3. Tidal stages associated with samples collected at OG-1 through OG-5 from 2003-2007. Note that the majority of exceedences were recorded on a flooding tide.

Wave Height. We next investigated the potential influence of nearshore wave height, measured at GoMOOS Buoy B (Western Maine Shelf), on bacteria scores. We would expect that days with greater wave heights would result in lower scores, especially along more open locations (i.e., OG-1 to OG-3, and OG-5). Wave data indicates that *when waves are 4 feet or greater, bacteria levels are generally lower at all locations* (Figure 5). However, there is an outlier at OG-2 that correlated with a northeaster, and for some reason levels remained high. When wave heights were less than 4 feet, there were a number of samples collected at OG-2 to OG-5 that had high bacteria levels, with OG-4 being the most common to have high levels. Therefore, it does appear that ***wave heights greater than 4 feet help keep bacteria levels lower***.

Wind Direction. Next, we investigated the role of wind direction on *Enterococci* levels. Wind directions were taken from the GoMOOS Buoy B (Western Maine shelf). Wind directions, recorded for each hour, were averaged over a 24 hour period so that a wind direction could be used to correlate with a sample date.

The limitation in this method is that wind directions vary throughout the day, and could be averaged to be a different direction than the wind at the time a sample was taken. At the same time, wind directions prior to a sampling time could have an influence on that sample, yet not be represented if only the wind direction at the time a sample was taken was used.

We examined all samples in relation to wind direction (Figure 6). This appeared to show a relationship between higher bacteria levels and wind from the southeast to southwest (170-220º from North). Twenty-five of the 37 samples (68%) that had bacteria levels that exceeded 104 col/100mL were collected when the wind was directed from the southeast to southwest. However, based on data for each month that samples were recorded from June 2004 through October 2007, the averaged wind blew out of these directions for approximately 44% of the overall wind data. Of the days that samples were collected, the wind was from these directions for 47% of the time. This is likely due to the fact that sampling occurs in the summer months, when these wind directions are dominant.

It is clear that, in general, ***when the wind blows out of the northeast, samples are cleaner along the beach*** than when the wind blows out of the directions noted above. The exception appears to be OG-2, which had two high samples when winds were out of the northeast and easterly directions (associated with the May 2005 northeast storms). It seems that winds from the east and northeast are associated with higher (storm) waves, which could create substantial mixing that dissipates concentrated bacteria along the beach and even in the river. ***Why OG-2 remained high under these conditions is not fully understood.***

Precipitation. Daily precipitation data was available from the NOAA National Climate Data Center for the Portland International Jetport. If we inspect direct correlation between rainfall recorded *on the day of sampling*, we found little clear pattern (Figure 7). If we then look at the total precipitation that occurred within 5 days before the day samples were taken, there is more to discern (Figure 8). There were 66 days when samples were taken that rainfall within the preceding 5 days was 1 inch or less (86% of all rainfall days). Of these days, 14 (21%) had at least one sample where bacteria levels were above 104 col/100mL. Of the days that rainfall within the five days preceding a sample *exceeded 1 inch* (11 days total), there were 6 days (55%) where bacteria levels were high. ***The highest recorded bacteria levels, mostly measured at OG-4, were when rainfall exceeded 1 inch*** (*specifically, greater than a cumulative 1.8 inches*). These wettest intervals of days also accounted for the highest recorded bacteria levels for OG-3, OG-2, and OG-5. For days where rainfall exceeded 1 inch and at least one value was above 104 col/100mL, winds varied greatly (northeast to northwest), and wave heights were generally less than 3 feet, aside from one value associated with the May 2005 northeast storms. Precipitation data also indicates that there is a potential lag time between rainfall events (up to 5 days) and high bacteria levels.

At the same time, it is interesting that there were other samples taken with high rainfall (above 1 inch) within the week and bacteria levels remained low at all sample locations. Wind directions during these times varied from 157-250º from North (southeast to southwest), and wave heights varied from 1.9-8.1 feet. As in other studies (Reeves et al., 2004; Sanders et al., 2005), ***high rainfall events can be followed by high bacteria levels*** but not in every case at Ogunquit Beach. ***Rainfall alone is not a complete predictor of high bacteria levels at Ogunquit Beach***.

DISCUSSION

Based on the results of the current study and this analysis, it is relatively clear that the Ogunquit River is the source of pollution for the MHBP sampling stations within the river and along the beach. The general trend of decreasing bacteria levels along the beach as one proceeds north away from the river is the greatest supporting evidence of this. However, it is also clear that different meteorological and hydrodynamic conditions play a role in influencing bacteria levels in the Ogunquit Beach area as they do elsewhere (Boehm, et al., 2004; Santoro and Boehm, 2007; Boehm and Weisberg, 2005; Ki, et al., 2007; Kim et al., 2004; Reeves et al., 2004; Sanders et al., 2005).

Wind direction appears to play a role in water quality at the sample locations along the open beach. Wind from the south, southeast, and southwest, would help move pollutants from the river along Ogunquit Beach. However, when wind blows from the north, northeast, and east, water quality, in general, is better. This may relate to additional mixing that would occur, especially along the open beach samples (OG1-3, OG5), associated with onshore waves. It seems that these wind directions also help move seawater down the Ogunquit spit and dilute the Ogunquit River water that has a tendency to have high bacteria levels.

We also noted that precipitation amounts appear to play a role in high bacteria counts. Specifically, rainfall within 5 days preceding sample collection in the amounts of 1 inch or more (with cumulative amounts of 1.6" and greater being the highest). This could be used as a predictor of suspect water quality, especially at OG-5, OG-4, and OG-3.

It also appears that weather patterns that create offshore wave heights of 4 feet or more (as measured at the GoMOOS Buoy B) will reduce bacteria levels at the open beach sites due to mixing. This would likely occur with wave approach from the east and northeast. However, wave approach direction may actually help transport bacteria along the beach, for example, if waves are from the southeast and coincide with an ebbing tide, bacteria could easily be transported to the north along the beach due to a generated northerly-directed longshore drift similar to California beaches (Kim et. al., 2004; Santoro and Boehm, 2007).

One unexpected finding was that the majority of samples that had high bacteria levels were taken on a *flooding* tide. This is not due to a bias in the data, since flooding tides account for 50% of the samples recorded, and ebbing tides the remaining 50%. This finding, however, is somewhat counterintuitive, since it is assumed that the river is the source of pollutants. This could potentially be attributed to the location of OG-4, which may not be capturing the ebbing freshwater mass that is likely to contain pollutants. What is clear is that pollutants that are most likely being released from the river mouth on an ebbing tide *are returning along the beach and back into the river on the flooding tide.*

A California study (Kim et al., 2004) found that calm periods during the night-time (generally when winds were calmest and wind-driven waves were lowest) likely allowed bacteria sourced from a river to be entrained within and just outside of the surf-zone on falling tides, allowing for the bacteria to be moved towards swimming beaches during the day by flooding tides, onshore winds, and waves. ***This may be occurring at Ogunquit Beach as well.***

One would think that the samples taken along the open beach on the ebbing tide would also capture higher bacteria levels, if the source is the river. Our current studies and closer inspection of the aerial photographs used as a base map for the area, show that there is a distinct trough in the beach within which ebbing river water appears to move north along the beach (Figure 9). *This feature could lead river water to potentially bypass the sampling location at OG-3 at certain tide levels.* It is possible that this trough is far enough offshore that collected water quality samples, taken on an ebbing tide (even mid-ebb) may not be capturing the higher bacteria levels (note that low ebb did have a high reading, Table 3) because the northerly-moving water mass may be concentrated on the eastern (ocean) side of the trough. This physical diversion of river outflow could be exacerbated by southerly and southwesterly winds, which would cause the water to move farther to the east.

CONCLUSIONS

Water quality samples and data collected by the Maine Healthy Beaches Program and analyzed by the Maine Geological Survey supports the hypothesis that **the Ogunquit River is the source of high *Enterococci* bacteria counts along Ogunquit Beach**. The following conclusions were drawn from the data:

- Bacteria levels are generally highest in the Ogunquit River and decline along the open beach and toward the northern end of Ogunquit Beach.
- Salinity data independently confirms that the source of pollution is water from the Ogunquit River.
- Water temperature alone cannot be used to predict water quality.
- Tidal stage is not a good predictor of bacteria levels at the Ogunquit River mouth.
- Tidal range is not a predictor of high bacterial levels at Ogunquit Beach.
- If bacteria counts are high, south or southwest winds can potentially spread bacteria up the beach to the north. A northeast wind appears to improve water quality along the beach.
- Offshore waves of 4 feet or greater appear to help keep bacteria levels lower.
- Rainfall in amounts of an inch or more within 5 days of a sample are likely to increase bacteria levels released from the Ogunquit River following about half of the high precipitation events.

RECOMMENDATIONS

We recommend that the Maine Healthy Beaches Program consider having a duplicate (OG-4A) sampling location within the Ogunquit River for a period of the next sampling season in order to investigate whether or not the current location of OG-4 is actually missing high bacteria counts on the ebbing tide. We recommend taking a second sample on the western bank of the river, adjacent to the bridge, or potentially just north of the bridge, on the eastern side (Figure 9). If sampling results from the new location are the same as the current OG-4, this sample location could be removed and additional costs and efforts of sample collection reduced.

Based on the data that we have analyzed, we also recommend that the MHBP work with the Town of Ogunquit to consider posting swim advisories after heavy (greater than 1 inch) rainfall events, regardless of whether or not a sample was taken.

We also recommend that the Program begin to work with the Town of Ogunquit to discern what the source of potential pollutants into the Ogunquit River might be such as failing septic systems that are activated during rain events only, urban runoff, leaking sewer pipes, or natural inputs from wildlife in the watershed, etc.

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