Southern California surf zone water quality: Fecal indicator bacteria and harmful algal bloom cells at the Santa Monica Pier and Malibu Surfrider Beach

Project Report by
TEAM MICROBE

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Abstract

Surf zone water quality is directly related to human health and that of the coastal ecosystem. Fecal indicator bacteria (FIB) and harmful algal bloom (HAB) cells are microbiological indicators of water quality that periodically occur in the surf zone of southern California waters. Negative impacts of high FIB and HAB concentrations include contaminated waters and marine life, ecosystem disruptions, beach closures, and human illnesses. Previous research has addressed parameters that increase FIB and HAB concentrations independently, yet none have examined if FIB and HAB are directly related. Our main study objective asks if a correlation exists between FIB and HAB, and how ecological/environmental conditions (onshore vs. offshore, salinity, total suspended solids, temperature, and precipitation) may affect their growth.

We collected water Monday through Thursday from Santa Monica Pier (SM) and Tuesday and Thursday at Malibu Surfrider Beach (MS) onshore and 100m offshore for 7 weeks. FIB concentrations were higher at MS onshore, whereas there was no onshore vs. offshore difference at SM. HAB abundances were higher offshore than onshore at both MS and SM. Onshore salinity and total suspended solids concentrations were lower at MS than at SM. Moreover, there was no significant relationship between FIB and HAB concentrations. Variability in FIB and HAB concentrations may best be explained by site differences and precipitous weather events.

Introduction

Surf zone water quality of California's coast has been a leading topic of public health and environmental preservation. Coastal waters are recognized for supporting fisheries, commerce, transportation, recreation, and provide a habitat for a wide range of marine organisms (Reifel et al., 2009). Poor water quality can damage each of these ecosystem services, thus leading to beach closures, economic losses, and contaminated waters. Two major groups of microorganisms that have an impact on coastal water quality and are considered water quality indicators are fecal indicator bacteria (FIB) and harmful algal bloom (HAB) cells.

FIB is not usually responsible for human disease, but the fecal matter from which it originates contains viruses, bacteria, and protozoa that are harmful to humans (Meyers et al., 2007). The U.S. EPA defines water quality standards for fecal contamination by the concentration of *E. coli* and *Enterococci spp.* in marine bathing waters. The health impacts of swimming in FIB contaminated water in the Santa Monica Bay include upper respiratory and gastrointestinal illness and severe skin rashes (Haile et al., 1999). In Los Angeles, pollutants like human and animal waste, toxins, and debris can accumulate over long periods of little rainfall. Previous studies have shown a positive correlation between high rates of storm water runoff and increased FIB levels, particularly due to rain following large dry-spells (Bertrand-Krajewski et al., 1998; Lipp et al., 2001; Boehm et al., 2002). The causes of the fluctuations in FIB concentration include sunlight, which stresses bacteria populations and causes cell death (Fujioka & Narikawa, 1982) as well as temperature changes, tidal variations, and the natural fauna in an area.

HABs only sometimes produce harmful toxins, although non-toxin containing blooms are also able to cause negative ecosystem or human impacts from development of high biomass, and subsequent oxygen depletion of waters upon death, or creation of surface foams and scrums

(Anderson et al., 2002). Factors that have been shown to support HABs include high phosphate concentrations, warm and calm surface waters (Sellner, 1997), nutrients from anthropogenic sources (Paerl, 1997; Smith et al., 2005), sea temperature changes (Chavez et al., 1999), fluid dynamics (Salomonsen et al., 1999), wind patterns, weather patterns including rainfall, and currents and tides (Schlacher et al., 2010). Although a range of possible influences have been identified, there is still little knowledge of how those factors interact and how they affect HAB cells in Southern California coastal waters (Burgman, 2005).

Most fecal bacteria reach the coastal ocean through the storm drain system, while HABs bloom sporadically in the surf zone due to anthropogenic influences (Anderson et al., 2002) or by natural phenomenon (Sellner et al., 2003). Past research has sought to understand the predictability of high levels of FIB and HAB independently (Roberts et al., 2007; Xu et al., 2010; Boehm et al., 2002; Anderson et al., 2002). However, this is the first study, to our knowledge, to examine the relationship between FIB and HAB concentrations in the surf zone. Furthermore, environmental conditions along an inshore-offshore gradient may help to explain controls of these two water quality indicators. Finally, a comparison of FIB and HAB concentrations at the Santa Monica Pier (SM) and at Malibu Surfrider Beach (MS) may help to understand the influence of anthropogenic versus natural processes.

Methodology

Temporal and Spatial Sampling Regimes

Throughout the paper, the term "location" will be used to refer to the two beaches, either Santa Monica Pier (SM) or Malibu Surfrider Beach (MS). The sampling "site" will be in reference to onshore or offshore, in which there will be a total of four sites: SM onshore, SM offshore, MS onshore, and MS offshore.

We sampled at 0800 +/- 2 hours PST, since concentrations of FIB have been found to be the highest in the morning (Dorsey et al., 2010), before sunlight degrades bacteria populations (Fujioka and Narikawa, 1982). The temporal sampling regime for Malibu Surfrider SB was twice per week (Tuesday and Thursday) and for Santa Monica SB, sampling was four times per week (Monday through Thursday) at 0800 +/- 2 hours PST. Although there were a few temporal gaps in our data, samples were collected for a total of 7 weeks at each site.

The spatial regime for sampling at Santa Monica Pier included one sample taken at the surface of the water, ankle-deep, making contact with the shore (point zero) and one surface sample taken further down the pier using a bucket, not to exceed 100 meters from point zero (Figure 1). The spatial regime for sampling at Surfrider SB included one surface sample taken at the mouth of Malibu Lagoon (point zero) and one sample taken from the surface (top inch) of the surf zone, no more than 100 meters from point zero in non-whitewater (Figure 1). Malibu Lagoon is a possible contaminant of the surf zone at Malibu Surfrider considering waste-water effluent from a nearby treatment facility and the abundance of birds. The samples were taken from the surface because a) this is where bacterial and algal blooms are most likely to be present, and b) this is where the interest to public health is greatest. Duplicate samples were taken once every four samples for each site.

Figure 1. Map of sampling locations, with Malibu Surfrider Beach to the west and Santa Monica pier to the east along the southern California coastline.

Enterococci (ENT)

We used the IDEXX method as described by Jeong et al. (2005) to quantify FIB concentration within six hours of water collection. Enzyme β-glucosidase and nutrients that promote ENT to grow were added to 10-mL of our water sample and diluted with distilled water to 100-mL. After mixing, the solution was poured into a sterile IDEXX tray and sealed. The samples were then incubated at 41 +/- 0.5 degrees Celsius for 24 +/- 2 hours. After incubation, the wells in which Enterococci bacteria consumed β-glucosidase were observed to fluoresce under UV light. Results were reported in units of most probable number (MPN) per milliliter. Uncertainty in FIB analysis may be attributed to the fact that fluctuations in FIB concentrations have been identified on timescales of decades, years, days, and hours (Boehm, 2007).

HAB cell counts

Water samples were gravity filtered through polycarbonate filters and stored in 10-mL of seawater with a formaldehyde buffer acting as a preservative for up to six months (Shipe et al., 2008). The sample was then observed under an Olympus BX6 light microscope to quantify HAB cells and other diatoms. HAB cells were quantified to genera in 1-mL aliquots in a Sedgewick-Rafter counting chamber with at least 100 cells counted per sample. Each sample was counted twice, by separate individuals. Their independent values were averaged to find the final HAB concentration (cells/L) of each sample in order to account for variation between random sample compositions and possible errors in taxa identification.

Salinity

A hand-held refractometer was used to measure salinity (ppt) after calibration with distilled water. It should be noted that one source of uncertainty was the resolution of +/1 1ppt on the refractometer.

Total suspended solids

To quantify total suspended solids (TSS), 250-mL of sample water was gravity filtered through a 0.6 micron nominal pore size glass fiber filter. TSS (mg/L) was calculated by subtraction after drying the sample at 103-105 °C for at least one hour.

Temperature

We recorded the temperature of the seawater immediately after collecting the sample water in the 1-L bottles.

Upwelling Index

Upwelling is the process by which Eckman Transport pushes cool, nutrient-rich waters to the surface and warm surface water away from the coast. Our upwelling index information was retrieved from the Pacific Fisheries Environmental Laboratory website, which calculates upwelling indices at 15 different locations along the Southern California coast on a 6-hourly, daily and monthly basis. Our information was taken from the location of 33˙ N and 119˙ W, which is 67 miles from SM and 76 miles from MS. The upwelling index takes into account the amount of wind stress 90 degrees from the coast divided by the Coriolis parameter (a function of the Earth’s rotation and latitude). This offshore component is considered to be a measure of the magnitude of water that is upwelled from the base of the Eckman layer. Negative values indicate downwelling, while positive values indicate upwelling with increasing magnitude demonstrating an increase in upwelling.

Service Learning Component

We worked together with Santa Monica High School’s Marine Biology, Heal the Bay Surfrider Club, and Team Marine students to process and analyze our FIB samples. They allowed us to use their lab, as we taught them about our project and how to do HAB cell counts. The SMHS students were also given the task of collecting water samples on Wednesday mornings at Santa Monica onshore and offshore.

Results

HAB

Santa Monica Pier

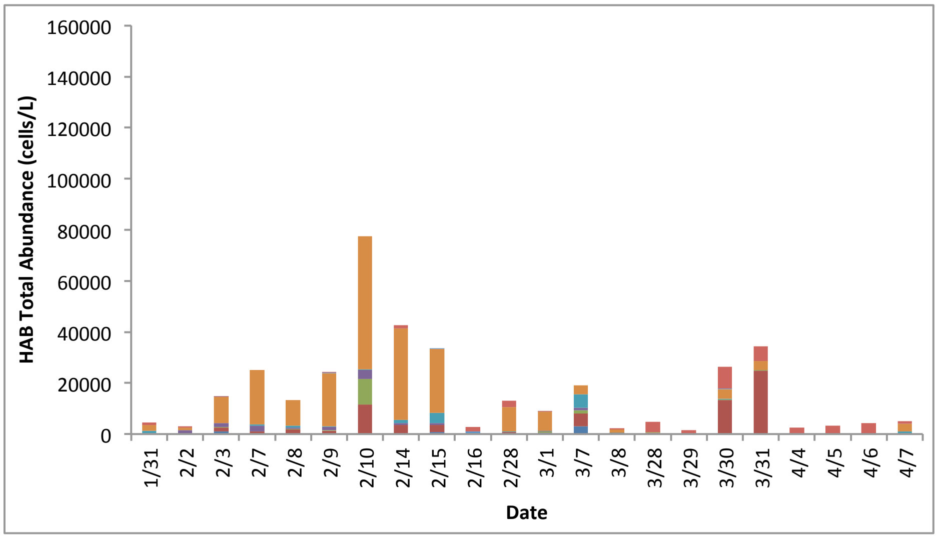

Figure 2. HAB Total Abundance at Santa Monica onshore (SM onshore).

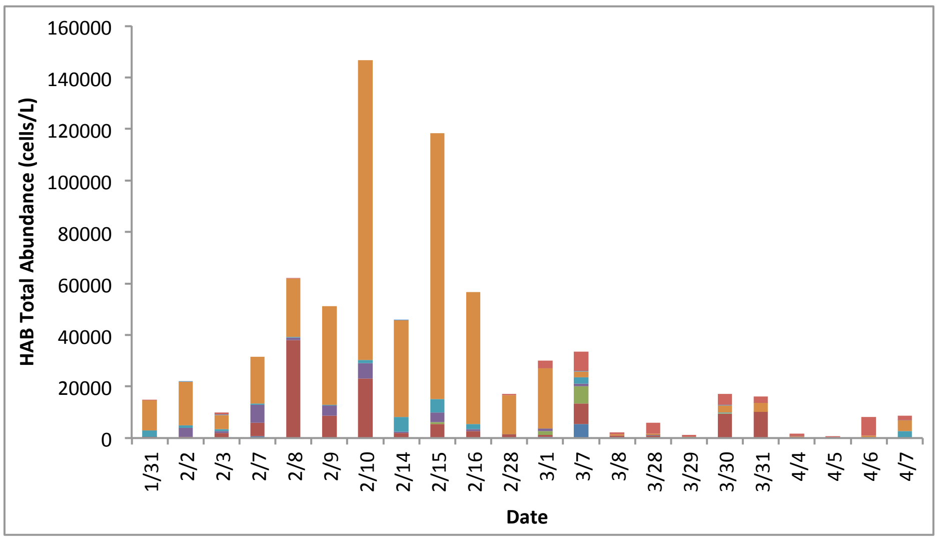

Figure 3. HAB Total Abundance at Santa Monica offshore (SM offshore).

At the Santa Monica site there were higher offshore HAB abundances than onshore for 16 out of the 23 total sample days (Figs. 2, 3), with relatively negligible differences on the other days. For example, the cell abundance offshore was about 20.3 times higher than onshore on 2/15, whereas onshore abundance was only 1.1 times higher than offshore on 2/14. Despite the differences in some of the magnitudes, the fluctuations showed similar peaks. There was a steady rise in the total abundance at SM between 1/31 and 2/10 followed by a decline from 2/10 to 3/8. The total HAB count at both sites peaked on 2/10 (147,000 cells/L offshore and 77,400 cells/L onshore). In the last two weeks, both sites showed a very low cell count with a small increase on 3/30 and 3/31.

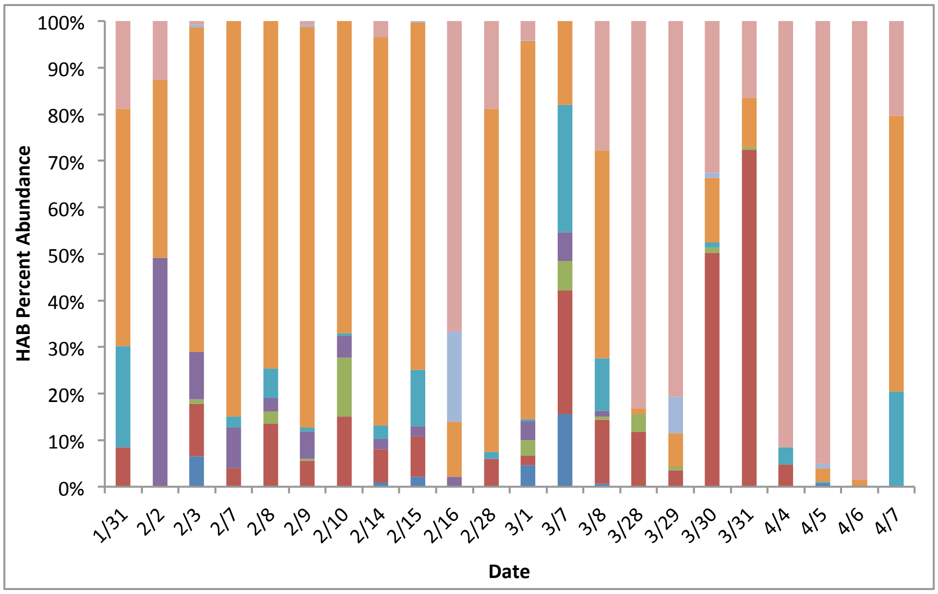

Figure 4. Relative percentage of HAB at SM onshore.

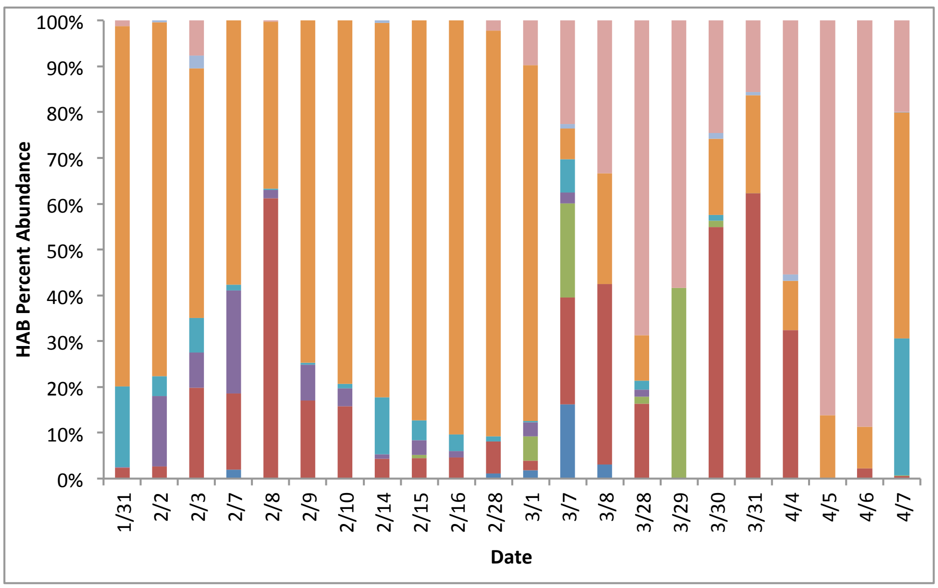

Figure 5. Relative percentage of HAB at SM offshore.

At SM relative abundances at both sites were very similar. Prorocentrum was the dominant taxon between 1/31 and 3/1. On 3/7, the composition of the HAB taxa was very diverse with Pseudonitzschia, Alexandrium, Gymnodinium, Akashiwo, and Dinophysis present at both sites. During the last two weeks of sampling (3/28 to 4/7), Pseudonitzschia was present in all samples and was generally the dominant species with exceptions on 3/30 and 3/31 where there was a spike in Ceratium and on 4/7 where there was an almost equal distribution of Pseudonitzschia, Prorocentrum, and Akashiwo.

Malibu Surfrider

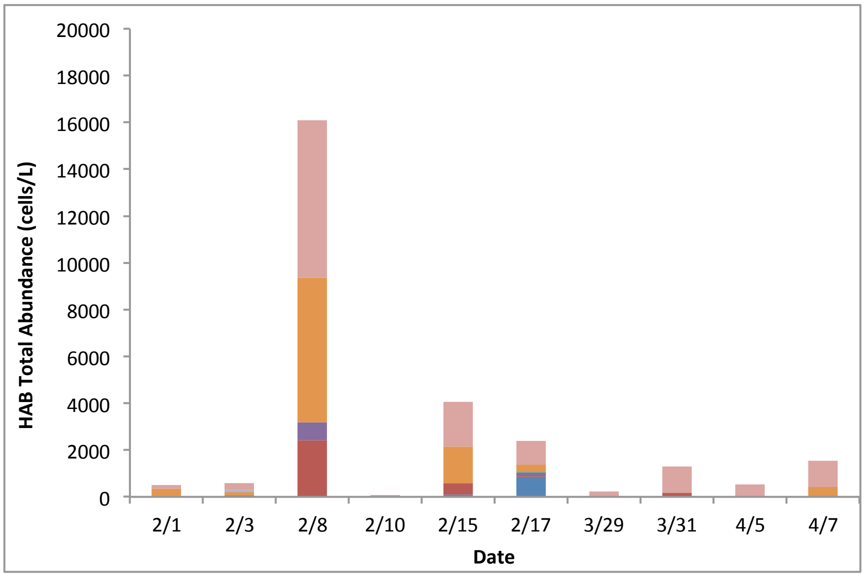

Figure 6. HAB total abundance at Malibu Surfrider onshore, (MS onshore).

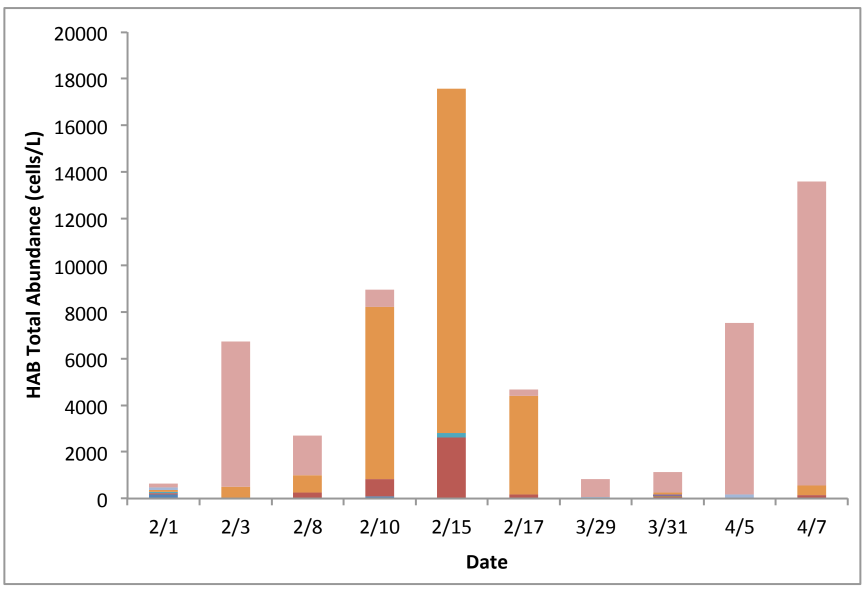

Figure 7. HAB total abundance at Malibu Surfrider offshore, (MS offshore).

Similar to the results found at SM, the total HAB cell abundances at MS were higher offshore than onshore for the majority of the days except on 2/8 where onshore abundances peaked (16000 cells/L, about 6.0 times greater than the offshore abundance) and on 3/31. The offshore HAB abundance peaked on 2/15 at 17600 cells/L, about 4.3 times greater than the onshore abundance. However, unlike at SM, MS offshore and onshore HAB abundances did not follow a trend as the cell abundances offshore fluctuated between high and low values while onshore values generally remained low.

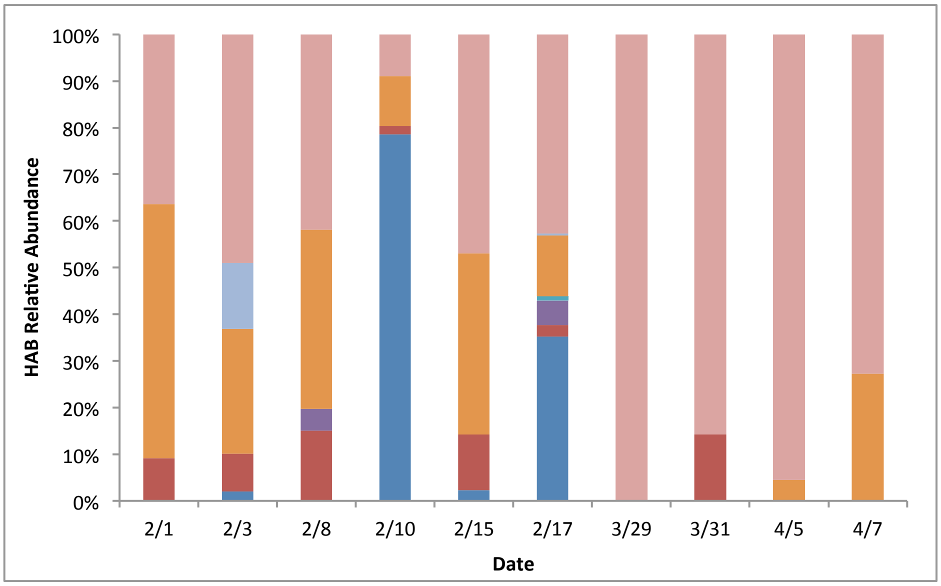

Figure 8. Relative abundance of HAB at MS onshore.

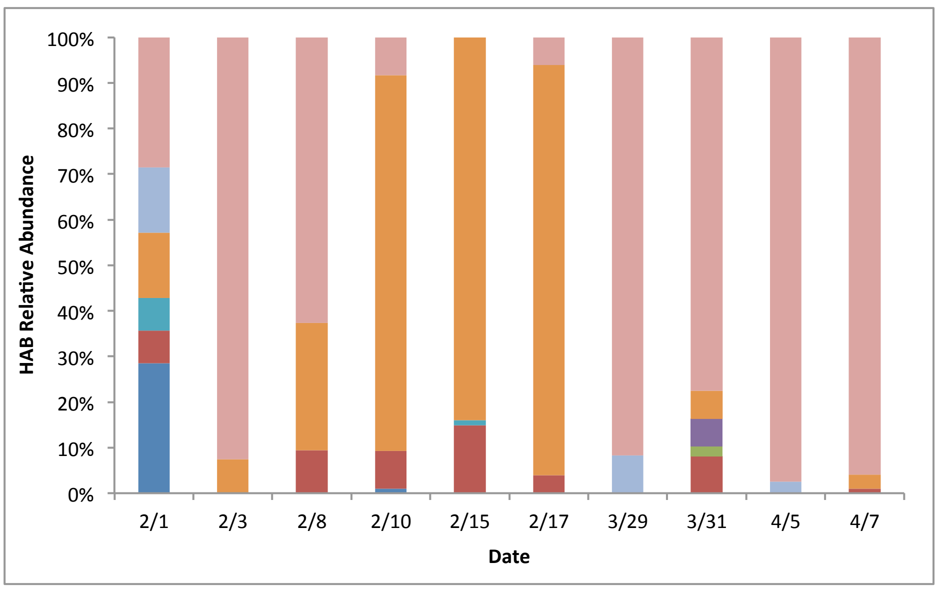

Figure 9. Relative abundance of HAB at MS offshore.

With the exception of the last four sample dates when Pseudonitzschia was dominant at both sites, the relative abundance of each taxon varied throughout the time series and between the sites. While both sites showed diversity in HAB taxa, there was not a single day in which both sites showed the same species richness. On 2/1 at MS, three taxa (Pseudonitzschia, Prorocentrum, and Ceratium) were present onshore while six taxa (Pseudonitzschia, Prorocentrum, Ceratium, Dinophysis, Alexandrium, and Akashiwo) were present offshore. Similarly on 2/17, Pseudonitzschia was dominant offshore whereas seven taxa were present onshore.

Santa Monica Pier versus Malibu Surfrider

The onshore HAB total abundance at SM was consistently higher by at least a factor of three relative to the total abundance at MS on all but one sample day. On 2/10, the SM onshore cell count was more than 1000 times greater than the MS onshore cell count (77400 cells/L at SM versus 50 cells/L MS). On the day that the MS onshore total abundance peaked, it was only 1.2 times greater than at SM onshore. HAB taxa at offshore locations varied significantly. MS offshore was dominated by Pseudonitzschia on most days while SM offshore was dominated by Prorocentrum on a majority of the days. The only day in which the relative abundances were similar was on 4/5 when Pseudonitzschia dominated both sites.

SM offshore HAB abundances were higher than MS offshore on 5 out of 7 sample days. On 2/10, the SM offshore cell abundance was larger than at MS by a factor of 13, (a difference of 136000 cells/L). The cell abundance was larger at the MS location on 4/5 and 4/7, but only by a small difference (7000 cells/L on 4/5 and 5000 cells/L on 4/7). On 2/15, although there was a peak in the cell abundance at MS offshore, the SM offshore cell abundance was still 6.7 times larger. The distribution of HAB cells at the offshore sites followed the same pattern as the onshore sites. Pseudonitzschia was the most abundant taxon during the seven sample days at MS, while Prorocentrum was the most prevalent taxon at SM. There were three days which showed similar distributions between offshore sites, with Prorocentrum dominating on 2/10 and 2/15 and Pseudonitzschia dominating on 4/7.

FIB

Santa Monica Pier

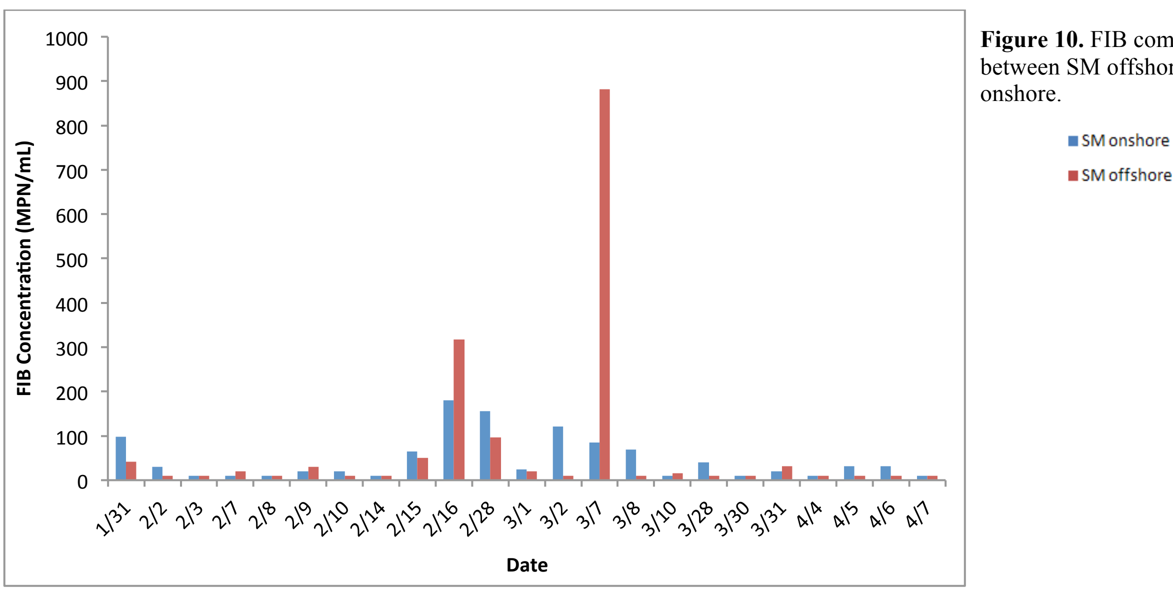

Figure 10. FIB comparison between SM offshore and SM onshore.

Over the majority of the sample days, *Enterococci* concentrations at SM onshore were higher than at SM offshore; however, *Enterococci* concentrations had higher maxima offshore. The onshore concentration peaked on 2/16 at 180 MPN/mL, but this was not higher than the offshore concentration on the same day, which was a relative peak at 318 MPN/mL. The absolute peak in the offshore concentration occurred at 882 MPN/mL on 3/7, which was 10 times greater than the abundance onshore and approximately 5 times greater than the peak onshore concentration.

Malibu Surfrider

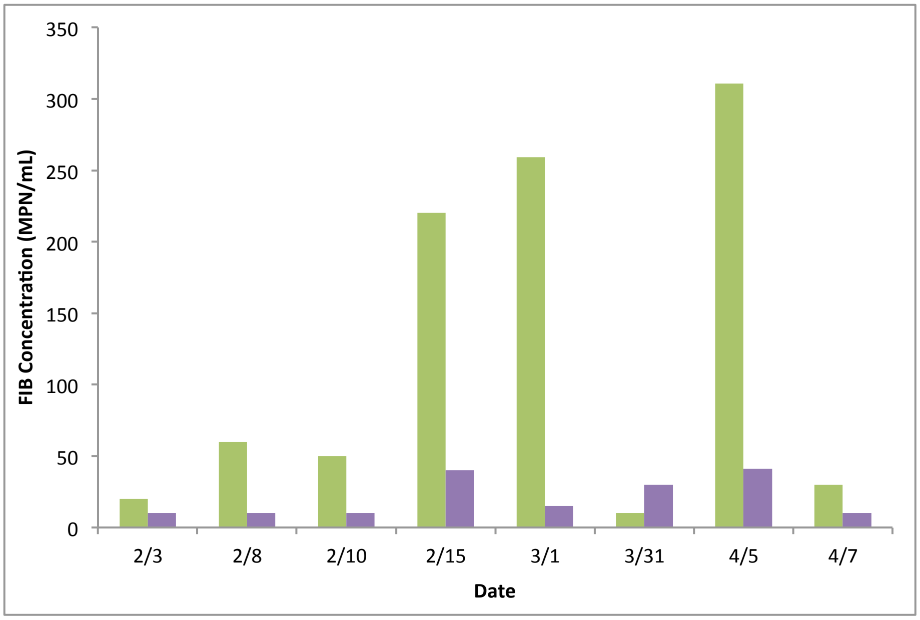

Figure 21. FIB comparison between MS offshore and MS onshore.

The *Enterococci* abundances at MS onshore were greater than those offshore for all but one sample day. With that one exception, the onshore *Enterococci* concentration was at least double the offshore concentration. The maximum concentrations for both locations occurred on 4/5 where the onshore concentration was 7.6 times greater than the offshore concentration (311 MPN/mL onshore and 41 MPN/mL offshore).

Santa Monica Pier versus Malibu Surfrider

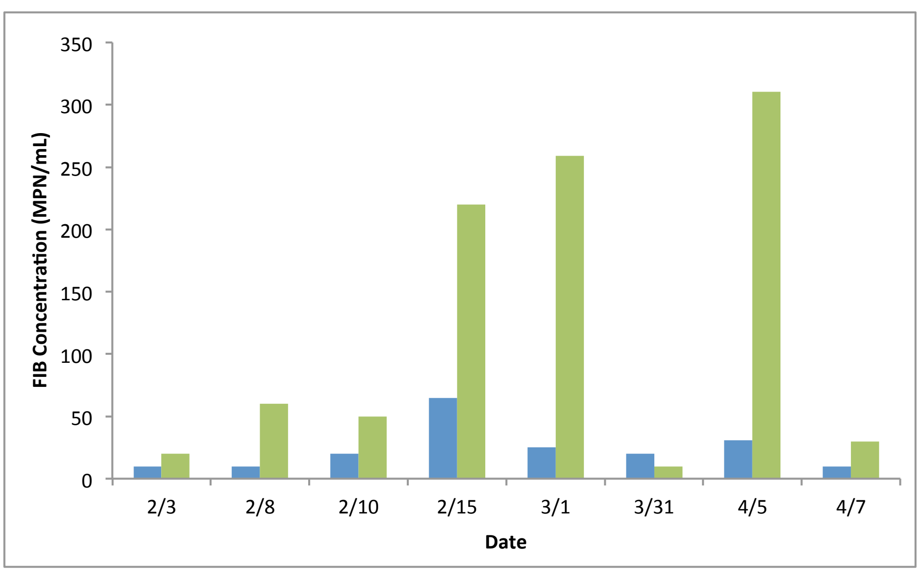

Figure 12. FIB comparison between SM onshore and MS onshore.

The MS onshore abundances were significantly higher on all sampling days except one. In this data set, SM onshore *Enterococci* concentration peaked on 2/15 at 65 MPN/mL, which was still only 30 percent of the MS onshore concentration on the same day. The MS onshore *Enterococci* concentration peaked on 4/5 at 311 MPN/mL, which was 7.6 times greater than the SM onshore concentration. On 3/1, there was also a significant difference between the concentrations, with the MS onshore concentration being 17.2 times greater than the SM onshore concentration.

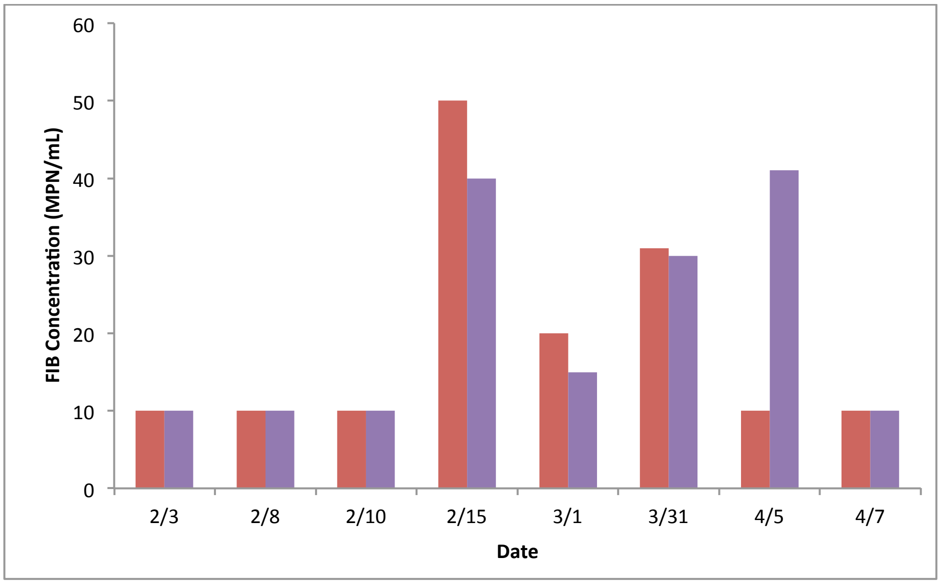

Figure 13: FIB comparison between SM offshore and MS offshore.

A comparison of both offshore sites shows that there was no significant difference between *Enterococci* abundance except on 4/5 when the MS offshore *Enterococci* concentration was four times greater than that at SM offshore.

<u>FIB versus HAB</u>

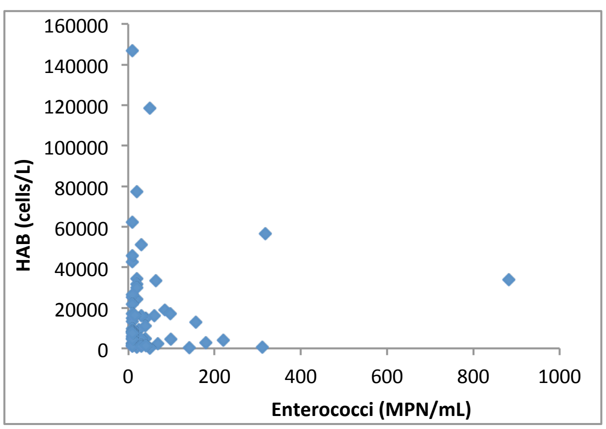

Figure 14. *Enterococci* versus HAB correlation plot.

There was no significant correlation between the *Enterococci* concentration and the HAB cell abundances ($r^2 = 0.0008$). Furthermore, there is no significant correlation between *Enterococci* and HAB concentrations from the SM onshore versus MS onshore analysis. The HAB total abundances at SM onshore were generally higher than those at MS onshore; however, MS onshore *Enterococci* concentrations were generally higher at MS onshore than at SM.

Environmental Conditions

Upwelling Index vs. HAB

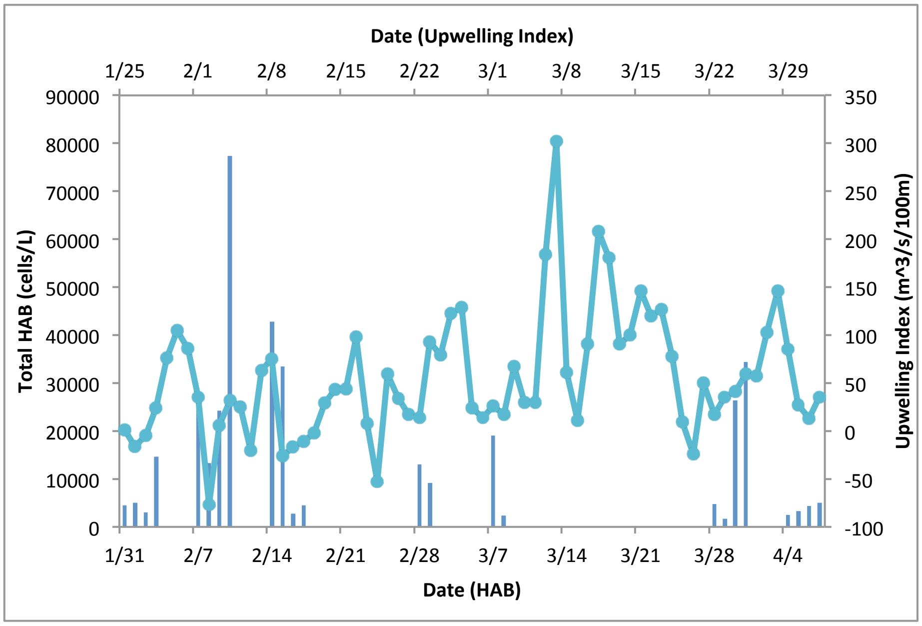

Figure 15. Peak analysis for a six day lag of the upwelling index and HAB at SM onshore .

Lag Time (Days)	R-Squared Value
0	0.059
1	0.173
2	0.038
3	0.010
4	0.119
5	0.052
6	0.032

Although there seems to be some correspondence between HAB abundances and upwelling indices with a 6 day lag, the regression analysis did not show a significant correlation between the coastal upwelling index and HAB cell counts for any of the lag times at SM onshore (Fig. 15). Since HAB abundance peaks best match upwelling peaks with a 6 day lag, it is possible that the 6 day lag upwelling and a combination of other environmental variables promote HABs. The R-squared values at the SM offshore site were similar to this and did not show a significant correlation ($r^2 = 0.033$), although there appeared to be a two day lag from upwelling maxima to higher HAB abundances (Figure 16).

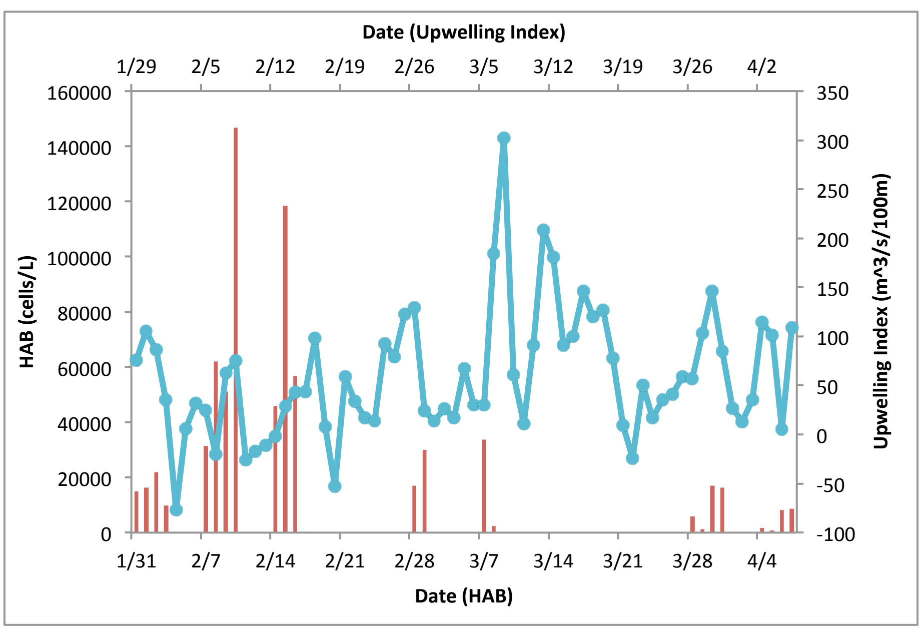

Figure 16. Peak analysis for a two day lag of the upwelling index and HAB at SM offshore.

Lag Time (Days)	R-Squared Value
0	0.033
1	0.119
2	0.122
3	0.097
4	0.247
5	0.088
6	0.057

Salinity and TSS

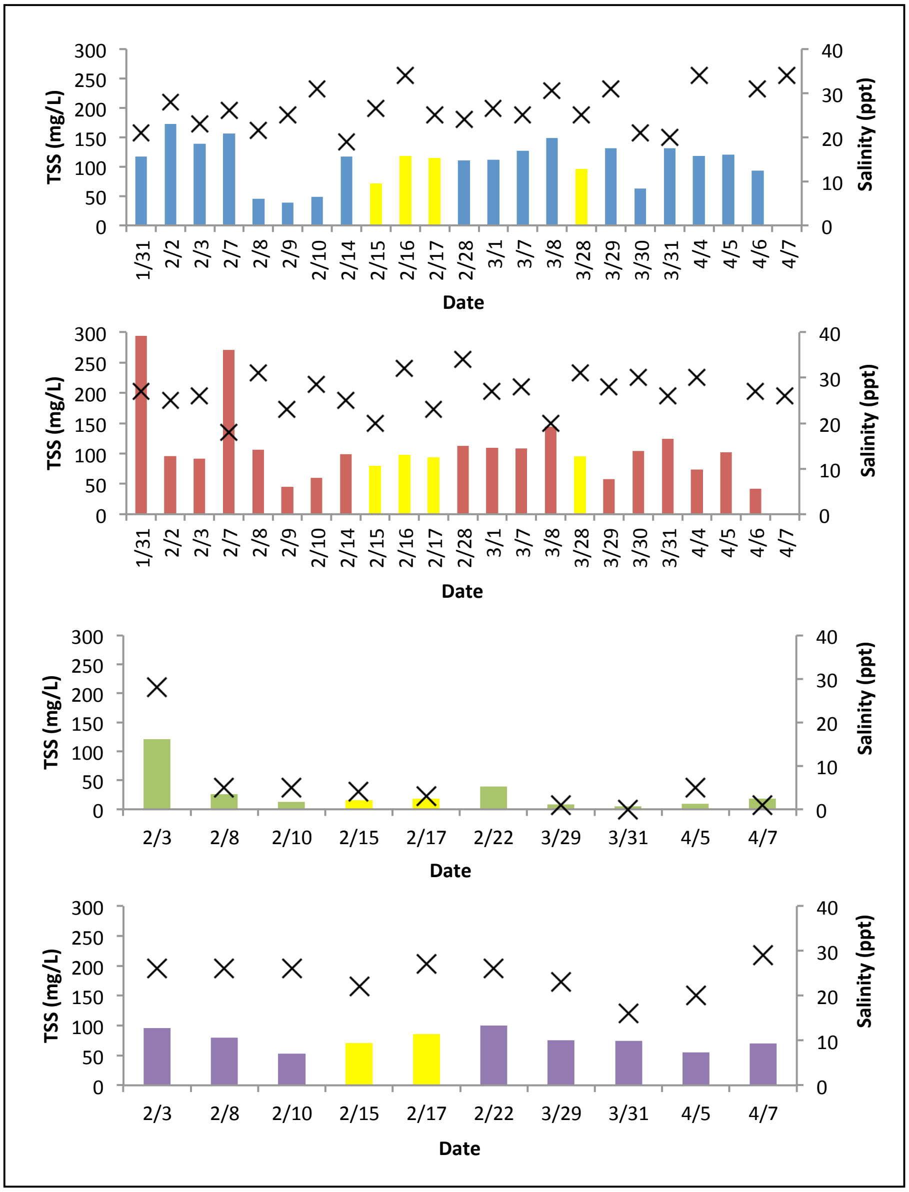

Figure 17. Salinity and TSS results for both the SM and MS sites with days that are affected by rain highlighted.

Overall, the salinity concentrations at the Santa Monica Pier were much higher than those at Malibu Surfrider, which may contribute to the higher HAB cell abundances found at the Santa Monica Pier. While SM onshore and offshore showed similar salinity concentrations, the difference between the MS onshore and offshore salinity concentrations was quite large. Compared to the average offshore ocean salinity near 24.1 parts per thousand (ppt) at MS offshore, the salinity at MS onshore was significantly lower (average concentration less than 5.0 ppt). MS onshore (under lagoon influence) was the location and site of the lowest HAB cell abundances and highest FIB concentrations. However, there is only a loose correlation between FIB and salinity at Malibu Surfrider onshore and offshore.

There were several important links between the environmental variables. Salinity at MS offshore was loosely associated with the corresponding upwelling index and TSS concentrations at the same site. In addition, SM onshore and offshore salinities followed a trend similar to the upwelling index, with high salinity generally corresponding to a higher upwelling index value.

Total Suspended Solids

TSS was consistently much lower at the Malibu Surfrider location. Like salinity, these lower TSS concentrations corresponded to the lower HAB abundance at both MS sites. In addition, low TSS concentrations also corresponded to high FIB concentrations at MS onshore. The TSS results at Malibu Surfrider have similar trends and peaks as FIB at the onshore and offshore sites; however, there is no significant correlation ($r^2 = 0.094$ onshore, and 0.00069 offshore) between the two variables.

Precipitation

According to data collected upon sampling, major precipitation events occurred at our sites on February 15, 17, 18 as well as March 2, 19, 20, 21, 23, 24, 25, 26. The longest consecutive days of rainfall occurred on March 23-26.

Discussion

Fecal Indicator Bacteria

Malibu Surfrider FIB data showed a significant increase in FIB concentrations at the onshore site relative to offshore. This could be attributed to the adjacent lagoon, which is home to a large population of sea-birds such as seagulls and other wildlife (Lee, 2003). Our samples were taken at the point where the lagoon meets the ocean, suggesting that high concentrations of FIB were leaving the lagoon and being dispersed/diluted as the discharge was carried into the ocean to our offshore sampling site and beyond. Did low salinity of this water also support the idea that this is relatively fresh water? On 3/31, our samples showed an unusually low concentration of FIB both onshore and offshore at MS. This sample date followed a 4 day heavy rain event (3/23-26). It is possible that the "flush" effect (Bertrand-Krajewski, 1998) from heavy and persistent rainfall carried away the normally stagnant FIB from the lagoon. This idea is further supported by the low salinity concentrations collected on 3/31, which indicates more freshwater in the sample. The onshore salinity was 0 parts per thousand (ppt) and offshore salinity was 16 ppt.

FIB at Santa Monica showed no consistent differences between onshore and offshore concentrations. However, the largest concentrations were seen offshore on 2/16 and 3/7. The elevated level found on 2/16 can be attributed to the precipitation events prior to that date. The 3/7 spike has unclear causes, based on the observed precipitation, TSS, and salinity levels. Because the onshore concentration on that day remained low, the FIB source most likely originated from the pier or further out. Boats sometimes were docked a few meters away from our offshore sampling site at the harbor patrol's dock. The septic systems in these boats, as well as the sewage systems on the pier may have contributed to leakage, thus creating spikes in FIB concentrations at our offshore site that would not be seen as easily onshore.

FIB differences between MS and SM may be partially explained by watershed differences, treatment procedures for stormwater runoff, and physical site characteristics. The Malibu Creek Watershed is mainly natural while the Ballona Creek Watershed that flows into the Santa Monica location is urban. FIB abundance is correlated with large populations within a watershed and the percentage of developed land/impervious concrete within a watershed (Mallin et al., 2000). Under these assumptions, the Surfrider sites should have significantly less FIB, but our results showed the opposite. FIB was lower at the urban watershed's sampling location. This observation supports the idea that the natural fauna including birds and other species associated with semi-stagnant water of Malibu lagoon contribute to a significant increase in FIB concentrations in the water draining to the ocean. One should note that Santa Monica Pier is under the influence of the Santa Monica Urban Runoff Facility, while Malibu's lagoon is itself influenced by a water treatment facility called the Civic Center Stormwater Treatment Facility. These treatment facilities strongly affect the amount of total suspended solids, nutrient loads, and possibly salinity, among other characteristics of water quality that might affect FIB growth. Accordingly, the largest differences in FIB can be attributed to environmental variables including watershed characteristics and precipitation events at each site.

Harmful Algal Bloom cells

Similar to the differences in FIB concentrations, the differences in overall HAB abundance can be attributed to watershed differences and environmental conditions at each location. The urban watershed of SM may contribute higher phosphate concentrations in the water that encourage the presence and growth of HAB cells (Sellner et al., 1997). The wave actions influence the environment where HAB grow (Sellner et al., 1997). Additionally, in terms of limiting HAB abundance, there may be a threshold for salinity and/or TSS that would allow algae to bloom at high levels. Due to the incoming freshwater from the lagoon, it is possible that MS surf zone water chemistry often does not meet this threshold. However, the peak in HAB abundance for MS offshore was reached on 2/15 (Figure 7), a day of high precipitation with average salinity/TSS concentrations. This increase must be attributed to other environmental factors such as sea temperature changes (Chavez et al., 1999), (sub)mesoscale fluid dynamics (Salomonsen et al., 1999), wind patterns, currents, tides (Schlacher et al., 2010), and accompanied lag times of any/all of these.

At both locations, HAB abundance was consistently higher offshore than onshore (Figures 2, 3, 6, 7). This may be attributed to calm surface waters which are less likely to disrupt HAB growth. Future research could compare HAB abundances in the surf zone to wave size and determine if larger waves correlate with lower relative HAB abundances. SM sample sites showed corresponding abundance peaks, while MS abundance peaks were at different days throughout the time series (Figures 2, 3, 6, 7). Water at SM is well mixed compared to the MS location with the input of lagoon drainage. This explains why a smaller difference is found between the onshore and offshore sites at SM.

The locations only roughly corresponded to compositions of HAB taxa. Nearly all high concentrations of Prorocentrum (Figures 4, 5, 8, 9) occurred during the winter months, suggesting that winter sea surface temperature promotes Prorocentrum growth. A threshold in salinity seemed to be reached at SM which allowed for a higher total abundance than at MS.

Also, Pseudonitzschia influxes occurred between March 23-26 (Figures 4, 5, 8, 9), after a lag time of about one week from the last major rain event. The one week lag time gave time for the algae to grow in the nutrient rich waters, eventually leading to a bloom in Pseudonitzschia. However, no changes in environmental variables such as TSS, salinity, or temperature were seen during this time. The first documented rain event occurred on February 15, 17, and 18. During this time, Prorocentrum was the dominant taxon before Pseudonitzschia became dominant. This follows the idea that winter sea surface temperatures support Prorocentrum growth and that a lag after the rain event led to a bloom in Pseudonitzschia.

Is there a relationship between FIB and HAB?

Results show no significant relationship between FIB and HAB concentrations at either site. On 2/15, there was a spike in both FIB and HAB data at MS onshore and also relatively high FIB and HAB concentrations at SM offshore. This date corresponded to a heavy precipitation event. Since this positive correlation was not observed at all times, other environmental variables including salinity and temperature may affect the growth of the two microbes. For example, there was a period of high HAB abundances during 2/9 - 2/15 at the SM onshore and offshore sites. During this time, the FIB concentrations were relatively low. According to our data, no single environmental variable can independently explain the high HAB abundances during 2/9 - 2/15. However, it is likely that FIB abundances can be explained by site differences and weather events. We have confirmed that FIB and HAB abundances are the result of complex relationships between several environmental variables, including but not limited to site differences and weather events. Moreover, specific taxa of HAB (and probably FIB) correlate to water chemistry differences more than others, on a significant scale.

Site Comparison

The greatest variation in water parameters occurred between onshore and offshore sites at Malibu Surfrider. FIB was much higher onshore, while HAB, TSS, and salinity were lower onshore. Mixing of the freshwater lagoon and ocean water occurs at the MS onshore sample site, which may explain why the parameters differed so much across 100 meters. Moreover, the lack of wave action at the Malibu onshore location and freshwater influence from the lagoon and ocean boundary can explain why the TSS and salinity results are lower than those at Santa Monica Pier. Beachgoers should avoid swimming near the outlet of the lagoon to avoid high FIB concentrations associated with various anthropogenic illnesses (Meyers et al., 2007). Future research could explore whether any anthropogenic FIB, particularly from leaky septic tanks throughout the Malibu Watershed, is adding to the FIB concentrations attributed to the natural fauna of the lagoon.

The lack of differences between onshore and offshore samples from Santa Monica suggests that water at this location is well mixed between sampling sites. Salinity results suggest that the storm-water drainage site under the pier was minimally active during our sampling dates. Even after large precipitation events, no significant change in salinity was apparent in the SM data. The runoff that reaches the pier must therefore travel from other active storm-water drains along the coast, including the Ballona Creek outfall (about 4 miles south of the SM pier). Our data confirmed that diverted flow from a drain under the pier may have deterred higher levels of FIB and other pollutants, thereby enhancing water quality.

Conclusion

Our objective to determine and quantify possible relationships between environmental variables and water quality indicator variables including the presence of harmful algal bloom cells and fecal indicator bacteria (*Enterococcus sp.)* produced varied results. The freshwater lagoon inflow at Malibu Surfrider (or lack thereof at Santa Monica) contributed significantly to low-salinity samples when flow into the ocean occurred. Although no direct correlation was found between FIB and HAB, our results have led to interesting conclusions that may be helpful for future research on water quality indicators. Future studies should attempt to quantify the influence each of these variables has upon specific taxa of microbiological surf zone water quality indicators. For example, one observation of note for further research includes a possible relationship between winter sea surface temperatures promoting growth of Prorocentrum, and the effect lag-time has on Pseudonitzschia growth.

FIB concentrations were consistently higher onshore than offshore at Malibu Surfrider. Low levels of salinity onshore at Surfrider were attributed to the freshwater influence of the lagoon, which may have contributed to high FIB (and low HAB) levels, considering possible salinity and/or TSS thresholds. At the Santa Monica Pier, FIB results were relatively similar to each other, although also greater onshore. Conversely, HAB concentrations were higher offshore than onshore at both locations – breaking wave action was found to have a significant negative correlation that was greatest onshore. Significant differences between HAB and FIB concentrations represented as individual beaches follow since the sites are approximately eleven miles apart; among others, temporal and spatial influences of (sub)mesoscale ocean features, physical differences in watersheds, and environmental factors affecting local water chemistry noticeably contribute to differences observed between HAB and FIB at each study location.

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