Monitoring the water quality of Lake Merritt, Oakland, Ca.: A study on species abundance in compliance with the water quality index

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Abstract The impacts of urban development and human interaction on the water quality of a man-made lake in Oakland were quantitatively examined in order to determine the suitability for aquatic habitation. Using a water quality index, samples of the water were collected and the various pH, temperature, water hardness (dissolved solids), ammonia, salinity, dissolved oxygen, and nitrate/nitrite contents were investigated. To complement the physical-chemical composition assessment, relative abundance of fish in each sampling site were also noted and the correlations determined. The principal adverse effects on Lake Merritt were related to storm water run off, nearby housing development and other construction, direct pollution from recreational activities on and around the lake, contamination from adjacent roadways, attempts at improving the water quality for specific species, and interactions with the ocean. Results showed that there is a direct relationship between high water quality (conforming the most to the water quality index) and higher relative species abundance of aquatic wildlife. It was correctly anticipated that the water quality is “best” in the southwestern most region (site 2), indicating high index values where the lake suffers the least impacts from its surroundings, but is greatly affected by the ocean (thereby showing high salinity levels). These findings show that the aspects of water quality that have been speculated to be greatly affected by activities around the lake have led to poorer water quality and therefore lower abundance of aquatic wildlife. Turbidity and water flow rate have also been qualitatively assessed and considered, although not thoroughly examined and may greatly influence species abundance as well.

Introduction

Every large body of water in world has been tainted and “polluted” by man’s presence, in one way or another (Gleick 1998). Even the simplest of interactions by man can leave a body of water affected adversely, inadvertently affecting creatures that rely on the water as a sanctuary and source of sustenance as well. Both point source and non-point source pollution have impacted water quality for recreation, drinking water, and aquatic life in all major bodies of water on Earth (USGS 2001). This is especially true in highly populated, industrialized nations, such as the United States. After three decades of efforts to protect the nation's waters, many of our waterways are still seriously degraded to the point where they are not only unfit for human consumption, but also inhospitable to many of their formerly indigenous aquatic wildlife (Gleick 1998). One reason for this is that biological monitoring and assessment programs are still not in place in most locations. Multi-faceted approaches, involving actions such as watershed restoration and pollution prevention, water aeration, and pollution point source removal are being taken by industries, communities, and several levels of government to address these problems (Alameda Flood Control Dist. 1982). The methods needed to remove pollution from these bodies of water, however, have not been agreed upon, nor has a universal method to monitor and judge the quality of the water. Many argue that healthy aquatic ecosystems are developed by focusing on the biological integrity of a system (Water Quality Associates 1992). Fish therefore, are often considered the best overall measure of a body of water’s health because their presence indicates successful functioning of many complex habitat systems including stream flow, water temperature, water quality and channel habitat (Water Quality Associates 1992).

Pollution, whether from a direct point source or indirectly, has serious impacts on the aquatic ecosystem. Drops in dissolved oxygen and increases in ammonia can create environments where only a limited number of species—those tolerant to such conditions will survive. This lowers species diversity and organism abundance (Buell and Girard 1994). The pollutants can also be hazardous to humans that are in contact with the water, through drinking, washing, or enjoying recreational activities in the water. Many North Americans are exposed to these risks (Alameda Flood Control Dist. 1982). It is therefore beneficial for community members to monitor the health of their streams, if not for the indigenous species, then for the health of the community. The two, however, are obviously interrelated. By cleaning up pollution for one cause, the effects would inevitably positively affect the other cause as well.

Situated in the heart of the city of Oakland, Lake Merritt, the nation's oldest wildlife refuge and a former sewer system for the entire city, has gone through tremendous changes since its first use by man. Yet, even today, it is still observed as having very poor water quality by most of its local residents (Water Quality Associates, 1992). Today, thousands of people still make contact with the water in the lake and have no idea how sanitary it really is. Many past observations have stated that the water quality is extremely poor and most believe that the water is inhospitable to aquatic wildlife. The latter has been proven untrue, as many fish still swarm to this site during certain seasons (Carlton 1966). This makes Lake Merritt a good urban model to test out methods for assessing water quality with both physio-chemical means and biological means, especially since no water quality monitoring of the lake has been done since the early 1960s. The examination of aquatic wildlife communities can be a useful means of monitoring changes occurring within the lake. I tested the hypothesis that water quality measurements and use of the water quality index, used in conjunction with a biological sampling regime can accurately determine water quality. I predicted that the water quality index had a strong positive relationship with the abundance of organisms found in the lake.

Methods

Study site and sampling locations Lake Merritt lies directly in the region considered to be the heart of Oakland, located in an area towards the north-western region of the city. Directly to the west of the lake is the San Francisco bay and towards its east are the Oakland Hills. The Oakland Hills consist of many streams, forming a watershed that empties directly into the lake. Within close proximity of the lake are many roadways and homes. Three freeways surround the lake to its north, east, and west, all located less than a mile away. Lake Merritt itself, is approximately three miles in circumference and at its greatest depth, about seven feet. (Fig. 1).

Figure 1. Lake Merritt (Oakland Museum of California)

Four sites were studied; each was believed to be a pointsource of possible pollution that affected the lake or a source that affected the water quality. The northern most region of the lake is the site where the streams from the Oakland Hills empty into the lake via culverts, pipes, and numerous man-made channels. This was chosen as Site 1. Site 2, the southwestern region of the lake, is the area closest to the Bay, with a direct pipe leading to and from the marine waters. The “Cleveland Cascade,” a water fountain installed to aerate the water was chosen as Site 3. It is located in the farthest west region of the lake. Site 4 was chosen in the area closest to a large roadway and believed to be in an area with high density of culverts and stormwater drains. Samples were taken from these sites from January 5 to April 1, 2001, on a weekly basis.

Field tests In this study, the water quality indicators, pH, temperature, nitrate, dissolved oxygen, fish abundance, and water hardness were measured and combined in a water quality index. Salinity was measured to assess possible influences on the other indicators, since it was noted that salinity often has adverse effects on each of the five indicators used to quantify the WQI. Salinity measurements would not be combined to derive the water quality index, however. At each site, the methods for on-site sampling of pH, temperature, nitrate, dissolved oxygen, water hardness, and salinity were utilized, approximately once a week, over the period of three months. Sampling was done during the evening, strictly between the hours of 5:00-7:00 PM and taken from a depth of two feet. Sampling was started in the northern most region and went according to site number. The following equipment was used: a thermometer, litmus paper, LaMotte brand ammonia and dissolved oxygen kit, AQ Pharmaceuticals brand nitrate and water hardness kit, and a hydrometer to estimate salinity. Whenever available, a Hoskin Scientific WTW PH340 digital ionmeter was used in addition to the other test kits. The majority of the samples were taken from a boat rather than at a dock.

Water quality index The water quality index (WQI) is derived from five of the seven components of the water that were deemed vital to the sustainability of aquatic wildlife in this study. The mean measurements for these five indicators were correlated with a relative index value for each individual parameter. These five components were then combined together, each multiplied with its magnitude of importance (given as a "weighing factor"). The WQI essentially, was a weighted average of these indicators. The weighing factors were as followed: dissolved oxygen = 0.17, temperature = 0.1, hardness = 0.7, nitrates = 0.10, and pH = 0.11. Salinity was grouped in with water hardness and therefore not accounted for, nor were ammonia levels. These parameters were measured and then converted into the WQI, the value of which can give an indication of the relative water quality of the lake and its ability to sustain aquatic life (USGS 2001). Once calculated, the measured test values were converted to a Q value by multiplying the measured values with the importance or weighing factor of the parameter (Aquatic Outreach Institute 1999). Based on a 100-point scale, the higher the Q value, the better the water quality. Both the Canadian water quality index and the one utilized by the USGS were used in deriving the one applied in this study. The one utilized in this study is different because it included four fewer indicators. This was due to the unavailability of necessary equipment as well as the lack of time to measure the other indicators. The original WQI was developed by the National Sanitation Foundation in an effort to interpret many water quality test results and condense the values in an index that would tell the overall quality of the body of water (Gleick, 1998). The Q values were categorized into five "value range" ratings: Excellent (Q value of 100-90), Good (89-70), Fair (69-50), Poor (49-25), and Very Poor (24-0).

Aquatic wildlife sampling Collection was done at each site using an aquatic drop net, with a wire frame measuring one square meter, with a net mesh size of 1/8". The bait used were earthworms available to the local fishermen. The net was baited with five worms during each sampling event and left for 15 minutes submerged, before it was pulled up and the species identified. This was done once per site, during each sampling event. Identification was done on site and the specimens were returned back into the lake. Fish identification was based on a guide of local species from the local fishermen as well as an outdated guide of species previously found in the lake (Carlton 1966). Many of the species mentioned in the book were no longer found in the lake and many which now inhabit the lake were introduced by man and not listed in the guide. The total number of individual organisms found at each site quantified fish abundance, whereas diversity was quantified by the total number of distinct species of fish found at each site. Aquatic sampling occurred at each sampling period.

Results

The results of the indicators measured on site are given in Table 1. Results are presented as an average of the measurements with the standard deviations. The ammonia, dissolved oxygen, salinity, and nitrate levels all varied greatly by site. Temperature was the only water quality indicator that exhibited little variance between the sites. There was an observed salinity gradient that decreased starting from the two southern sites (Sites 2 and 4) up to the two northern sites. As the sites got farther from the ocean inlet, the salinity decreased. The water density decreased from an average of 1.020 g/ml (SD = 0.002) at site 2 to 1.013 (SD = 0.004) at site 1. The pH levels were consistent between all of the sites with the exception of site 2.

	Site 1		Site 2		Site 3		Site 4	
	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD
Temperature (ºC)	16	1.69	15.59	1.67	15.95	1.75	15.36	1.50
PH	8.4	0.11	7.9	0.17	8.4	0.18	8.4	0.17
Salinity (g/ml)	1.013	0.004	1.020	0.002	1.015	0.004	1.018	0.003
Dissolved Oxygen (ppm)	8.31	0.48	9.08	0.69	9.42	0.66	8.18	0.33
Nitrate (ppm)	3.54	1.07	3.23	1.48	4.03	1.13	4.12	0.89
Water Hardness (ppm)	422	27.68	394	20.52	421	26.92	430	31.89
Ammonia (ppm)	0.025	0.018	0.018	0.010	0.028	0.028	0.035	0.026

Table 1. Water quality measurements and indicators from Lake Merritt sampling sites.

Due to the low levels of ammonia detected at each of the sites, the deviations were high. The average ammonia levels were negligible at all sites, with the greatest average being 0.028 ppm (SD = 0.028 ppm) at site 3. Water hardness was similar between sites 1 and 3, but variedly slightly with sites 2 and 4. A similar trend was exhibited in dissolved oxygen measurements, where sites 1 and 4 had similar levels, but mildly different from that of sites 2 and 3, which also were similar in oxygen content.

Calculating q-values with these measurements with the use of the water quality index yielded four distinct numbers (see table 2). Sites 1 and 3 had very similar values, obtaining water quality indices of 74 and 75, respectively. Site 2 had the highest q-value, with a water quality index of 81, although it shares the same associated water quality assessment with sites 1 and 3, obtaining a reading within the range labelled as “good water quality.” Site 4 had the lowest q-value (q value = 69) and was the only site to have been assessed with “fair water quality.”

	Site 1	**Site 2**	**Site 3**	**Site 4**
Q values	74 (Good)	81 (Good)	75 (Good)	69 (Fair)

Table 2. Calculated Q values and associated rating

Bioassessment data depicts the combination of total number of organisms found at each site, in relation to the WQI, from the entire study, which consisted of 12 sampling dates. Species abundance was also noted but not calculated. While there were numerous organisms caught at each site, the species diversity was fairly low in any given site or sample (Figure 2). The number of organisms found at each site varied marginally while the variation between the number of species from each site was almost non-existent, except for the case of site 2. Site 2, with a sample of 44 fish, had by far the greatest number of organisms caught and was also the closest to the bay inlet. Sites 1 and 4 had a similar number of organisms caught (24 and 26 respectively), whereas site 3 had by far the least, with only 18. The number of different species caught at site 2 was only slight greater than that of the other sites however. Site 2 had seven species of fish caught in the sampling event, while site 1, 3, and 4 all had five species. The species were not the same, however, since sites 1 and 3 had significantly lower concentrations of salinity.

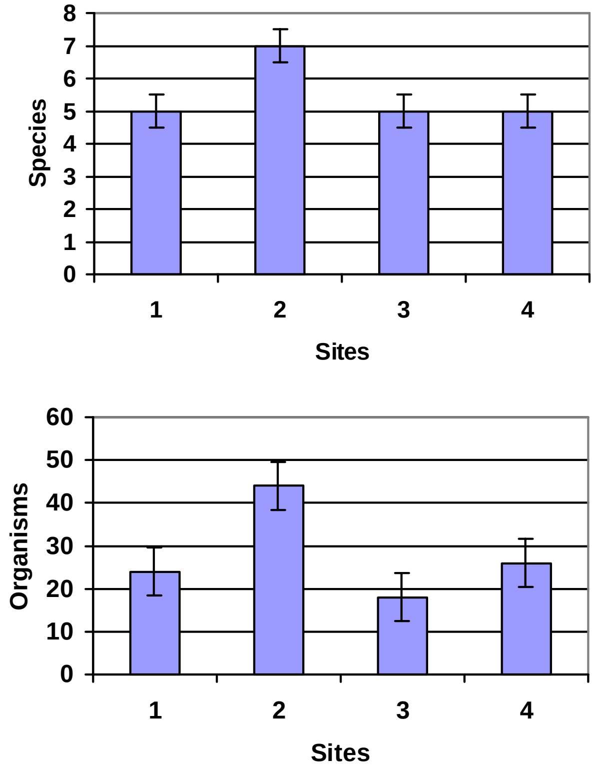

Figure 2. Species abundance and diversity with standard error.

Discussion

Results of this study indicate that there is a relationship between water quality and the number of organisms found in Lake Merritt. The difference in numbers of species caught in relation to the water quality indicators was easily detectable by the simple tests performed on site. It was evident during the on site sampling events that there were clearly more fish located in regions that closely conformed to the WQI's notion of good water quality. Bioassessment and q-value calculations confirmed that areas closer to the ocean tend to have noticeably higher water quality and also provided evidence that man made systems for improving water quality were not able to substitute for sites further distances away from marine waters in a brackish environment. This conclusion was derived from both the conformity to the WQI and the abundance of fish found in sites 1 and 3. Site 3 had the aeration fountain which seemingly served its purpose and influenced water quality by improving the amount of dissolved oxygen found on site. Site 3 had the greatest levels of dissolved oxygen of any of the four test sites, yet its q-value was about the same as that of site 1 and the number of organisms found on site was the least.

A similar study found that the use of a water quality index was a viable means of assessing water quality and detecting the health of a habitat for aquatic wildlife (USEPA 1986). However, it was also noted that all of the nine water quality indicators utilized in water quality appraisals were considered vital, and that all had to be used in order to obtain proper evaluations (USGS 2001). It is possible that without the other water quality indicators weighted into the WQI, the assessment of Lake Merritt's water quality may be incorrect. It has been observed that certain aspects of water quality offset one another, therefore changing the value of the q-values obtained in this study (Biological Sciences Department 1977).

This data obtained in this study contrast most previous assessments of Lake Merritt's water. Previously, the water quality had been evaluated with different means, usually depending on visual cues and other human senses such as that of smell. Other factors influencing these decisions included the amount of algae noticeable on the surface of the water as well as overall clarity of the water. These evaluations reached the conclusion that the water quality in Lake Merritt was very poor and in dire need of human intervention (Alameda Flood Control Dist. 1982). Physical observations would tend to agree with such conclusions (Water Quality Associates 1992). This however, is prior to recent attempts at improving the water quality of the Lake for its inhabitants (Water Quality Associates 1992). The fact that water quality varies with time must also be established since factors such as tidal flow, [ambient air] temperature, wildlife feeding habits, and flow rate vary both daily and seasonally within Lake Merritt (Biological Sciences Department 1976). All parameters, however, were fairly consistent, over five with low standard deviations, with the exception of nitrate and ammonia readings, which could be attributed to natural fluctuations between samples or error in calibration of equipment. Salinity was not directly measured but quantified with density readings only to ensure consistency between sites and sampling dates because significant fluctuations would disrupt levels of all the other indicators. Salinity itself, however, is generally a poor indicator of water quality in brackish water because its variation in level does not affect the water's suitability of habitation by fish but rather, allows fish with different requirements to reside in different regions of the same body of water (Carlton 1966.).

There was found to be a direct relationship between the number of fish caught and the proximity to the ocean. Since all of the species caught, with the exception of one, are generally regarded to be marine fish, most were believed to have entered into the lake from the bay. The further away from the bay inlet, the fewer the number of fish were present. This could be due to the fact that the water directly entering from the bay had exhibited the "best" water quality, obtaining the highest q-value. Site 3 had better water quality than site 1 and 4, but this was attributed to the water fountains artificially placed in this location by man to deliberately improve/alter water quality. The fountain accomplished its goal, but did little to improve fish abundance because the majority of fish in the lake prefer waters with greater salinity (Carlton 1966). Site 1, also being farther away from the bay inlet, had a greater number of organisms available than site 3, even with lower salinity, because the fish found there were generally regarded as fresh water fish and less tolerant of the higher salinity levels. Site 3 was the only site to have fish that were not from the ocean. It is believed that many of these fish at site 3 originally came from the streams in close proximity to this region. Site 4, even with the worst q-value, had an equal number of species as site 1 and 3, and a greater abundance of organisms than either site. This was most likely due to its extremely close proximity to the bay. Many of the fish found in the lake only venture far enough to feed, never leaving the regions close to the bay inlet. One key feature of these fish found at site 4 is their ability to resist harsher conditions and be more tolerant of pollution and changes in their environment (Carlton 1966). This may be the reason why there were so many fish at site 4—the fish there were simply able to survive in an area where less “hardy” fish could not, so they therefore thrived in such regions. Apparently, salinity and other water quality indicators may have played a vital role in explaining why there were so many more species in regions with only “fair” water quality in comparisons to sites with better water quality. Especially since two out of the three sites with water quality considered “good” had markedly fewer species.

It is recommended that more precise instrumentation be used if further measurements are to be taken and the study to continue. Turbidity/total suspended solids, water flow rate, benthic macroinvertebrates, ambient air temperature, and aquatic insects should also be quantified, since regions with drastically different measures of these attributes seem to also affect species abundance and species type. Many studies note that benthic macroinvertebrates and aquatic insects tend to be a stronger indication of a natural body of water’s ability to sustain life. A stronger plan of cross-referencing the water quality index and species abundance should also be implemented. Noting that the water quality index has no meaning of its own but was intended only to be used as a reference in comparison to other similar bodies of water or the same body of water over an extended period of time, further samples over a greater time interval should be taken and compared to those which have already been taken. This would be a better means of assessing the water quality of the lake and surveying whether it is in a state of decline or improvement.

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