Water Quality Monitoring of Maryland's Tidal Waterways

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The Chesapeake Bay

Courtesy of Maryland Department of Natural Resources

The Chesapeake Bay

- Largest estuary in the United States
- Stretches from Havre de Grace, Maryland to Virginia Beach, Virginia
- Houses more than 3,600 species of plants and animals
- Commercial and recreational resource
- Connected to many tributaries, spanning 5 states

Department of Natural Resources (DNR)

MARYLAND
DEPARTMENT OF
NATURAL RESOURCES

- Recognizes that the health of the society and the economy are dependent on the health of the environment
- Strives to preserve, protect, restore, and enhance the environment for this and future generations

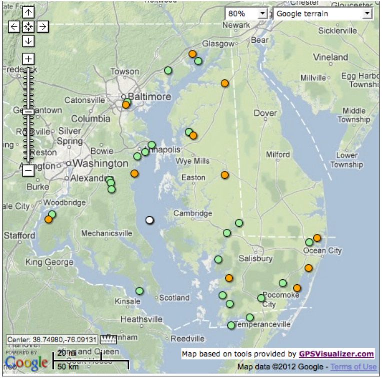
We want to assist the DNR in analyzing and assessing the water quality of Maryland's tidal waterways

Monitoring Stations and Parameters

- Various types of stations, spanning several decades
- 38 continuous monitoring station data from 2011
- Readings taken every 15 minutes (majority of stations)

Important Parameters:

- **Dissolved Oxygen**
- **Turbidity** (water clarity)
- **Chlorophyll** (algae growth)
- **pH** (water acidity)



Courtesy of www.eyesonthebay.net

What Constitutes "Failure"?

Courtesy of www.eyesonthebay.net

Parameter	Failure Threshold	Time Frame
D. Oxygen (severe)	< 3mg/L	June to September
Dissolved Oxygen	< 5mg/L	June to September
Turbidity	> 7 NTU	April to September
Chlorophyll	$> 30\mu$g/L	April to September
pH	< 5.5 or > 8.5	April to September

Station Status

Wilcoxon Signed-Rank Test

- Nonparametric test that compares the station's median to the failure threshold
- In terms of a particular parameter, is the station "Good," "Bad," or "Borderline?"
- Assumes the distribution is symmetric
- In the statistic below, R_i denotes the rank of $|x_i - thresh|$

Test Statistic: $$S = \left| \sum_{i=1}^{m} [R_i \cdot \text{sign}(x_i - thresh)] \right|$$

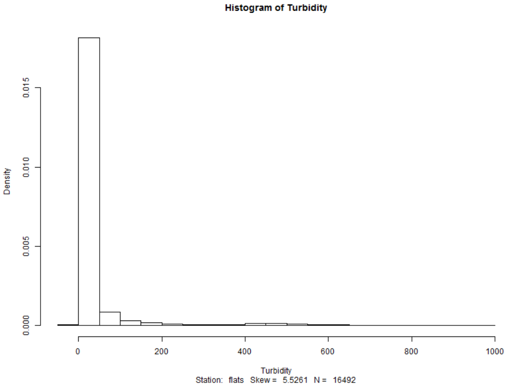
Wilcoxon Results

Wilcoxon Assessment Table (a subset)

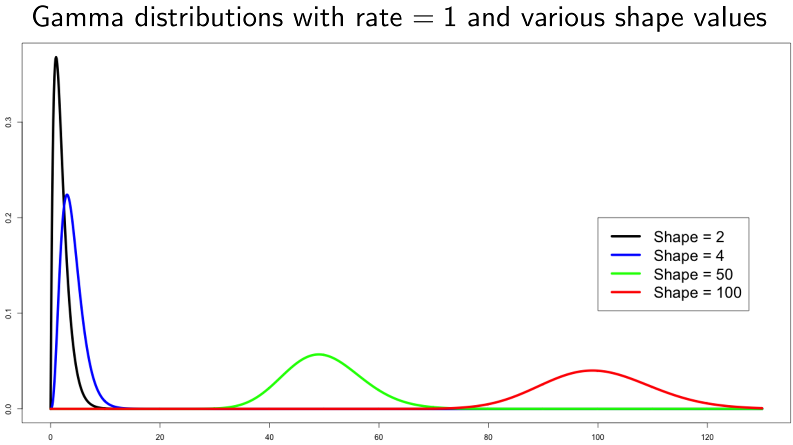
Station Name	DO5	DO3	Turbidity	Chlorophyll
AnnapolisCIBS	Good	Good	Good	Bad
Betterton	Good	Good	Good	Good
Big Annemessex	Good	Good	Good	Good
Bishopville	Bad	Good	Good	Bad
Budds Landing	Good	Good	Good	Bad
Chesapeake Y. Club	Good	Good	Good	Bad
Corisca River	Good	Good	Good	Bad
Downs Park	Good	Good	Good	Bad
Flats	Good	Good	Good	Good
⋮	⋮	⋮	⋮	⋮

Simulation

- The Wilcoxon Test assumes the distribution is symmetric, but not all parameters are distributed as such
- Assesses the validity of the Wilcoxon's Test and the effect of violating assumption of symmetry



Gamma Distributions



Simulation Results

Wilcoxon Type I Error

Wilcoxon test applied to samples drawn from the gamma distribution **before and after log-transformation**

shape \ rate	Before 1	Before 10	After 1	After 10
2	0.8737	0.8692	0.2183	0.2207
4	0.5054	0.5042	0.1003	0.0977
10	0.1716	0.1701	0.0407	0.0335
50	0.0304	0.0145	0.0131	0.0297
100	0.0204	0.0128	0.0116	0.0205

Ranking of Stations

Ranking of Stations

- In order to rank stations, one must perform a comparison between each pair of stations to see whether the stations are significantly different
- This results in $\binom{n}{2}$ tests where n is the number of stations
- In order to control for Type I Error over the whole study, multiple comparison tests must be used

Tukey Test

Tukey Test

- Tukey's Test is a commonly used multiple comparison test
- It performs multiple ANOVA's using a test statistic q in the Studentized Range Distribution
- Being based on ANOVA tests, it is designed to test means
- One can use proportions to make a Tukey-like test of proportions by using a variance transformation

$$p' = \frac{1}{2}\left[\arcsin\sqrt{\frac{X}{n+1}} + \arcsin\sqrt{\frac{X+1}{n+1}}\right],\ SE = \sqrt{\frac{410.35}{n_A+0.5} + \frac{410.35}{n_B+0.5}}$$

Test Statistic: $q = \frac{p'_A - p'_B}{SE}$

where X is the number of readings above the threshold and n is the number of observations in the sample (station).

Bonferroni

Bonferroni's Adjustment

- Bonferroni's method is to adjust α for all $\binom{n}{2}$ tests
- The probability that there is a false-positive in events A or B is $p(A) + p(B)$
- Thus since there are $\binom{n}{2}$ tests, by dividing α by $\binom{n}{2}$ we get that the total probability of a Type 1 Error is α
- Therefore the adjustment is simply to let $\alpha = \frac{\alpha_0}{\binom{n}{2}}$ where α_0 is the chosen α

Benjamini-Hochberg

The Benjamini-Hochberg Method

- While the Bonferroni method uses the traditional Type I Error definition, the Benjamini-Hochberg method uses what's known as the Familywise Type I Error
- Familywise Type I Error: The probabily of "false discoveries"
- α is the fraction of tests with false-positive rejections
- The method is as follows:

1. Sort the p-values $p_{(1)} \dots p_{(m)}$ where m is the number of tests
2. Finding the largest k such that $p_{(k)} \leq \frac{k}{m}\alpha$
3. Reject $p_{(1)} \dots p_{(k)}$.

Oxygen (5mg/L) — Ranking of continuous monitoring stations with respect to its Percent Failure (% Fail) , the Tukey Test (TT), the Bonferroni Test (Bonf), Benjamini-Hochberg Method (BH), and the Bayesian Ranking Method (BRM).

Station Name	% Fail	TT	Bonf	BH	
				% Fail	Mean
Betterton	0	1	1	1	4
Havre de Grace	0	1	1	1	5
Flats	0.0001	1	1	3	2
⋮	⋮	⋮	⋮	⋮	⋮
Little Monie	0.8021	36	36	36	37
Masonville (bottom)	0.8040	36	36	36	36
Goose (bottom)	0.8981	38	38	38	38

Conclusions

Conclusions

- **Wilcoxon**— The Bay and its tributaries appear to be in good condition for all parameters except chlorophyll
- **Simulation**— Log-transformation of the data substantially reduces Type I error, however the error is still large
- **Ranking**—The Bonferonni Adjustment appears to be the most conservative grouping method while the Benjamini-Hochberg Method appears to be the least

References

- For complete details of all our projects, please see the Project Technical Report: HPCF–2012–12 `www.umbc.edu/hpcf` > Publications.
- For more information about the parameters and stations, please visit: `www.eyesonthebay.net`