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A Report Card of Water Quality for the Elkhorn Slough estuary in 2013

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AUTHOR AFFLIATION

At the time the report was prepared, Mercado was enrolled in the professional Masters program at California State University Monterey Bay, and an intern at the Elkhorn Slough National Estuarine Research Reserve (ESNERR). Haskins and Preisler were on the staff of ESNERR.

DISCLAIMER

ABOUT THE ELKHORN SLOUGH TECHNICAL REPORT SERIES

The mission of the Elkhorn Slough Foundation and the Elkhorn Slough National Estuarine Research Reserve is conservation of estuarine ecosystems and watersheds, with particular emphasis on Elkhorn Slough, a small estuary in central California. Both organizations practice science-based management, and strongly support applied conservation research as a tool for improving coastal decision-making and management. The Elkhorn Slough Technical Report Series is a means for archiving and disseminating data sets, curricula, research findings or other information that would be useful to coastal managers, educators, and researchers, yet are unlikely to be published in the primary literature.

EXECUTIVE SUMMARY

In order to create a report card that describes the current status of Elkhorn Slough Estuary's waters, we analyzed Elkhorn Slough Reserve's water quality data from 2013. We selected nine parameters measured monthly at 24 sites, and searched the literature for appropriate thresholds. Our scoring systems examined the scope, frequency and magnitude with which thresholds were exceeded and produced composite index values (ranging from 0 to 100) as well as letter grades for each sampled site and each parameter. The resultant values were spatially interpolated to generate thematic maps that provide a visual, simplified representation of water quality data analysis. These scores and maps can be used by community members and decision-makers to identify areas of least and most concern. Overall, this report card is a tool intended to help advance knowledge about Elkhorn Slough water quality issues and encourage voluntary and regulatory actions to improve it. While our approach provides a meaningful summary of overall water quality, it cannot replace the detailed analysis of environmental monitoring data nor should it be used as the only tool for management of water bodies.

INTRODUCTION

Water pollution is an environmental problem that threatens the health of aquatic systems and consequently their ability to continue providing valuable goods and services. Elkhorn Slough estuary along the central coast of California is highly polluted and faces associated ecological concerns (Caffrey et al. 2007, Hughes et al. 2011). It is currently included on the US EPA's 304(I) list of impaired waters, is listed as a 303(d) water quality limited water body by the Central Coast Regional Water Quality Board and classified as a water body where beneficial uses of receiving waters have been impaired according to the California State Water Resources Control Board. Despite these designations, insufficient actions have been taken to prevent or reverse the degradation of water quality. This can be partially attributed to the lack of pressure for action from a public that is largely unaware about the state of Elkhorn Slough waters. As an attempt to educate non-scientific or non-technical audiences about water quality issues we developed a project with the purpose of using water quality data to create a report card.

Water quality monitoring in the Elkhorn Slough area started in 1988 through the Volunteer Program developed originally by researchers at Moss Landing Marine Laboratories and was subsequently coordinated by the Elkhorn Slough National Estuarine Research Reserve (ESNERR) with support from the Elkhorn Slough Foundation (ESF) and the Monterey County Water Resources Agency. Under this program, 24 stations located throughout the slough are sampled monthly for: temperature, salinity, conductivity, dissolved oxygen, pH, turbidity, nitrate, orthophosphate, ammonium, free ammonium, chlorophyll a and algal cover. Some of data are submitted to a publicly available national database (http://cdmo.baruch.sc.edu/), for anyone interested in data review or analysis. In addition, these data are usually incorporated into studies conducted by ESNERR researchers, visiting researchers, and students (undergraduates and graduates). We were interested in making the data accessible to others outside the scientific community by providing a simplified version of data analysis in the form of a report card that assigns different grades to different sites.

METHODS

For a description of data collection field methods and laboratory work see Hughes et.al 2011. Any additional information is available upon request by contacting the author(s) or the water quality monitoring program.

Water quality scoring systems

Since there is no single metric that can describe the overall quality of a body of water, an alternative option is to calculate a composite index that quantifies the extent to which different water quality measurements deviate from normal ("ideal") concentrations (Rickwood and Carr 2007). We were interested in identifying a scoring system capable of calculating composite index values and that satisfied two conditions: had been exposed to extensive review and produces results that could be comparable across locations. We found several systems and after evaluating advantages and disadvantages, we selected the Water Quality Index (WQI) scoring system, which has been applied at the global scale by United Nations (WHO 2004) and regionally by the Bay Institute (Bay Institute 2003) and Ventura County (Sercu 2013). The selected approach calculates index values for each sampling site ranging from 0 to 100, where 0 is the worst index score and 100 the best index score.

The WQI scoring approach was developed by the Canadian Council of Ministers of the Environment (CCME) in 2001, as a tool to simplify the reporting of water quality data (CCME 2001). They recognized that while traditional technical reporting consisting of parameter by parameter data is valuable to water quality experts and managers, it was often inaccessible and confusing to non-experts. This new approach offers the alternative to provide meaningful summaries of overall water quality, accessible to managers as well as lay people. Some of the advantages include: the ability to combine measurements of different parameters in a single number, the ability to produce a single unitless value from various measurements in a variety of different measurements units, and the facilitation to communicate results. Disadvantages include but not limited to: loss of information on single variables, oversimplifying the complexity of water quality, and loss of information on interactions between variables. CCME recommends to not apply the WQI scoring approach to score sites where less than four parameters are sampled and/or where measurements are recorded less than four times during the index period (usually a year).

A modified version of the WQI called Magnitude and Exceedance Quotient (MEQ) approach is currently being adopted by the Central Coast Ambient Monitoring Program (CCAMP) to evaluate the health of watersheds. CCAMP is interested in looking at scores of individual parameters instead of calculating a single score that accounts for all parameters. Thus, the MEQ is more appropriate for detailed parameter by parameter analysis. We decided to apply both methods, the WQI to produce a general summary of water quality per site and the MEQ for a more detailed analysis of each parameter.

The first step in the WQI and MEQ is the selection of the water quality parameters that will be incorporated in the calculations. Then, selecting one threshold value for each water quality parameter, where the threshold is an existing guideline or standard value usually established by a government agency with a specific purpose. We found existing standard values listed in the Central Coast Basin Plan, CCAMP technical reports and US EPA for the purpose of protecting aquatic life in cold and/or estuarine waters (Table 1).

Table 1. List of parameters and existing thresholds. COLD = cold water aquatic life, EST = estuarine water aquatic life.

Parameter	Threshold	Beneficial Use	Source
Ammonia	0.1 mg/L	EST	US EPA 1999
Ammonia (Unionized)	0.025 mg/L	COLD and EST	Basin Plan
Algal Cover	20%	COLD	Worcester et.al 2010
Chlorophyll a	15 µg/L	COLD	Worcester et.al 2010
Nitrate as N	1.0 mg/L	COLD and EST	Worcester et.al 2010
Orthophosphate as P	0.13 mg/L	COLD	Williamson R 1994
Turbidity	25 NTU	COLD	Sigler et.al 1984
Dissolved Oxygen	7 to 13 mg/L	COLD	Basin Plan & Worcester et.al 2010
pH	7 to 8.5	COLD and EST	Basin Plan

Data analysis

The WQI has three components:

Scope is the percentage of parameters that do not meet their threshold at least once during the predetermined timeframe, relative to the total number of parameters measured.

Frequency is the percentage of individual measurements that do not meet their thresholds divided by the total number of samples.

Amplitude is the amount by which failed sample values do not meet their thresholds.

Each WQI component is calculated individually then combined to produce an index value per sampled site.

$$Scope = F_1 = \left(\frac{number\ of\ failed\ parameters}{total\ number\ of\ parameters}\right) \times 100$$

$$Frequency = F_2 = \left(\frac{number\ of\ failed\ samples}{total\ number\ of\ samples}\right) \times 100$$

Amplitude is calculated in three steps:

1a. $excursion_1 = \left(\frac{Failed\ value}{Threshold\ value}\right) - 1$, when the sample value should not exceed the threshold.

1b. $excursion_1 = \left(\frac{Threshold\ value}{Failed\ value}\right) - 1$, when the sample value should not fall below the threshold.

2. Normalized sum of excursions (nse)

$$nse = \frac{\sum_{i=1}^{n} excursion_1}{\#\ of\ samples}$$

3. Asymptotic function that scales the nse from thresholds to yield a range between 0 and 100

$$Amplitude = F_3 = \left(\frac{nse}{0.01nse + 0.01}\right)$$

Calculate index value:

$$WQI\ (site) = 100 - \left(\frac{\sqrt{F1^2+F2^2+F3^2}}{1.732}\right)$$

The MEQ has two components:

Frequency is the percentage of individual measurements that do not meet their thresholds divided by the total number of samples.

Magnitude (equivalent to amplitude) is the amount by which failed sample values do not meet their thresholds.

CCAMP has eliminated the term scope for two reasons: inconsistent data availability across sites and because they are doing their calculations at the level of the parameter not the site. CCAMP is interested in scoring sites from multiple monitoring programs, which not necessarily monitor the same set of parameters and in some cases less than the minimum number of four parameters are recorded per site. By removing scope CCAMP can assign an index score to each parameter per site rather than an overall water quality score.

The final equation is:

$$MEQ\ (parameter) = 100 - \left(\frac{\sqrt{F2^2+F3^2}}{1.414}\right)$$

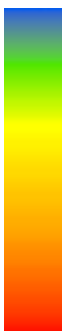
Data collection occurs once a month during daylight hours, thus the measurements recorded do not capture potential day to night variability which can result in overestimates of index values for

DO, turbidity and pH. Of particular concern was DO because previous analysis of DO data at Azevedo Pond North has revealed that the pond becomes hypoxic almost every night but these hypoxic events are not captured when using only monthly sampling data. In an attempt to account for this variability we applied the DO threshold (7 to 13 mg/L) to the monthly data and to our 24 hour data collected every 15 minutes at four stationary sites. We compared the index values obtained from each dataset and adjusted the threshold range for monthly data as appropriate to match the results of 24 hour data. The modified threshold range was 7.5 to 11 mg/L.

Spatial analysis

Once index values were calculated they were spatially interpolated using ArcGIS 10.1 to create a thematic map showing variation in water quality levels across the slough. Table 2 displays the symbology used in the interpolation and the corresponding index value, condition, grade (letter) and description in terms of water quality.

Table 2. Grading scale used in the Water Quality Index



Index Value	Condition	Grade	Description
95 – 100	Excellent	A	No virtual threat or impairment. Water quality conditions very close to natural or pristine levels.
80 – 94	Good	B	Only minor degree of threat or impairment. Water quality conditions rarely depart form natural or desirable levels.
65 – 79	Fair	C	Occasionally threatened or impaired. Water quality conditions sometimes depart form natural or desirable levels.
45 – 64	Marginal	D	Frequently threatened or impaired. Water quality conditions often depart from natural or desirable levels.
0 – 44	Poor	F	Almost always threatened or impaired. Water quality conditions usually depart from natural or desirable levels.

RESULTS

The WQI approach was applied to calculate an index value for each of the 24 water quality sampling sites accounting for nine parameters. According to the calculation results (Figure 1), 13 sites scored “F”, three sites scored “D”, six sites scored “C”, two sites scored ”B”, and no sites scored “A”. Lowest index values corresponded to Tembladero Slough (21) and Strawberry Road (22) and highest values to Vierra (80) and South Marsh (80). All sites located within the Southern Estuary area received failing grades, while the best scores were identified at the Lower Elkhorn Slough area.

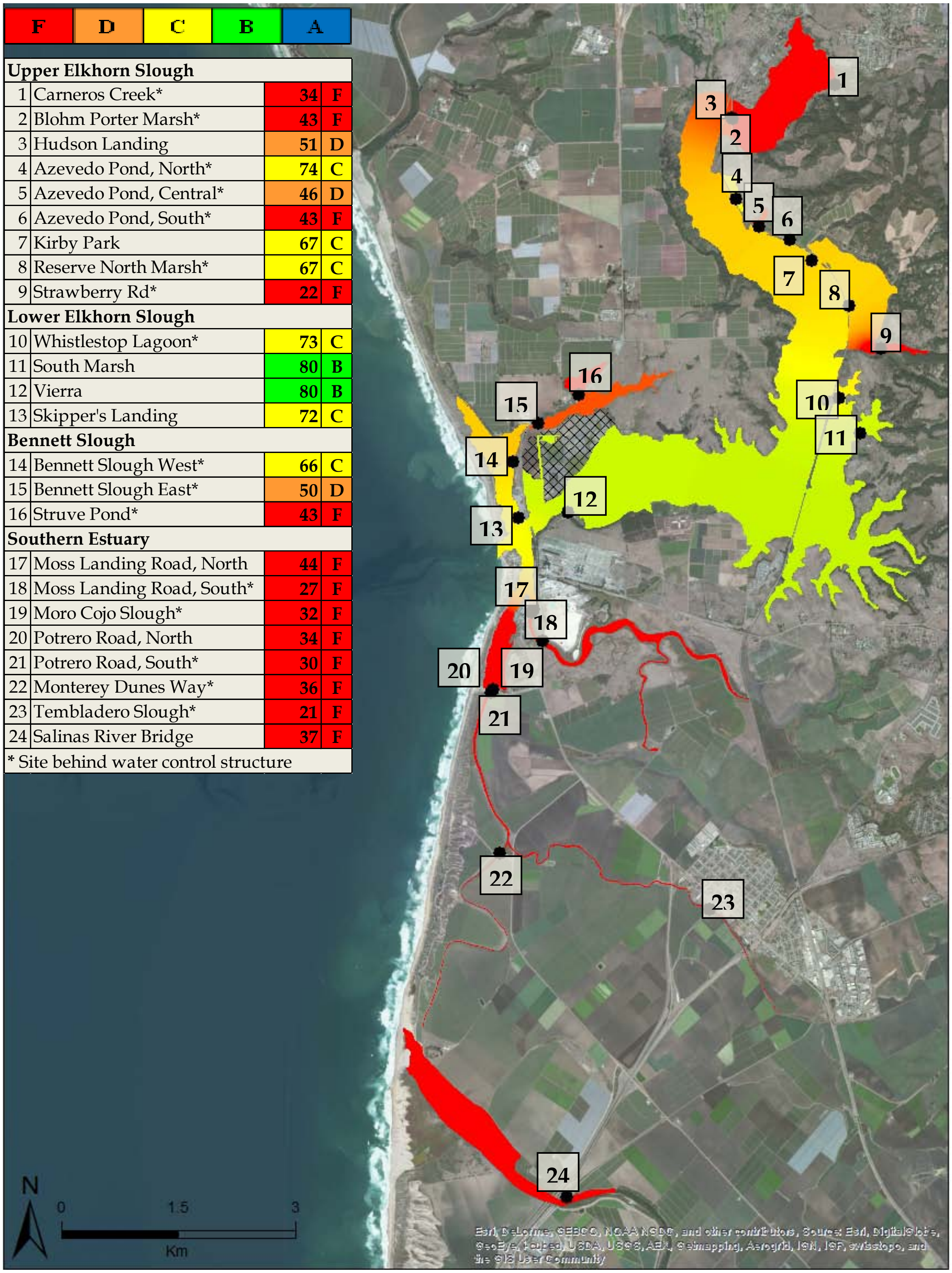


Figure 1. Resultant grades and spatial interpolation of index values calculated using the Water Quality Index approach.

MEQ results (Table 3) indicate that the parameters of least concern across the majority of the sampled sites were free ammonia and algal cover. On the other side, parameters of higher concern were dissolved oxygen which scored below 79 for all sites and phosphate which scored "F" or "D" for more than half of the sites. Sites in the Southern Estuary region received the lowest grades for ammonia, nitrate, phosphate, turbidity and pH, relative to the other three regions, while sites the Lower Elkhorn Slough region received the higher parameter by parameter grades out of the four regions.

Table 3. Magnitude and Exceedance Quotient results

No data	0-44 = F	45-64 = D	65-79 = C	80-94 = B	95-100 = A

Code	Name	Ammonium	Free Ammonia	Chlorophyll a	Nitrate	Phosphate	Algal Cover	Turbidity	DO	pH
Upper Elkhorn Slough										
1	Carneros Creek*	47	71	27	92	25	100	46	30	43
2	Blohm Porter Marsh*	48	100	66	60	40	89	90	55	80
3	Hudson Landing	43	100	61	93	34	100	73	69	95
4	Azevedo Pond, North*	94	100	92	100	100	100	100	52	82
5	Azevedo Pond, Central*	54	100	48	100	100	49	80	15	64
6	Azevedo Pond, South*	100	100	10	100	4	100	24	28	62
7	Kirby Park	88	100	81	94	100	100	100	63	94
8	Reserve North Marsh*	100	100	87	100	100	100	94	52	88
9	Strawberry Road*	34	79	10	100	77	87	29	1	17
Lower Elkhorn Slough										
10	Whistletop Lagoon*	88	100	71	100	100	100	100	61	94
11	South Marsh	92	100	90	100	100	100	100	54	99
12	Vierra	100	100	92	100	100	100	94	76	100
13	Skipper's Landing	65	100	87	80	100	100	100	54	96
Bennett Slough										
14	Bennett Slough, West*	70	100	100	81	94	100	100	53	77
15	Bennett Slough, East*	100	100	7	100	100	70	18	48	26
16	Struve Pond*	85	92	No data	100	88	73	25	46	41
Southern Estuary										
17	Moss Landing Road, North	48	100	No data	8	37	100	87	78	92
18	Moss Landing Road, South*	13	51	No data	37	54	45	54	41	74
19	Moro Cojo Slough*	49	68	No data	63	46	52	67	61	53
20	Potrero Road, North	47	100	No data	4	27	100	14	56	86
21	Potrero Road, South*	61	100	No data	2	13	100	9	63	61
22	Monterey Dunes Way*	70	100	No data	5	17	100	44	50	41
23	Tembladero Slough*	30	63	No data	1	12	100	17	46	77
24	Salinas River Bridge*	90	100	No data	5	13	100	69	41	37

* Site behind water control structure

It is important to note that the average of all MEQ values per site does not equal to the WQI value, this is because our MEQ approach is only intended to provide a parameter by parameter analysis which allows us to identify parameters of higher and least concern at each site and not to produce overall water quality grades. The average of MEQ values produces considerably higher grades than the WQI values. If interested in matching the MEQ results to WQI results, scope (number of failing parameters) needs to be added to the MEQ calculations. This can be done by calculating the average of MEQ values and the score for scope (using the formula $100 - \left(\frac{\sqrt{F1^2}}{1}\right)$, or 100-$F_1$ for simplification), then averaging these two values.

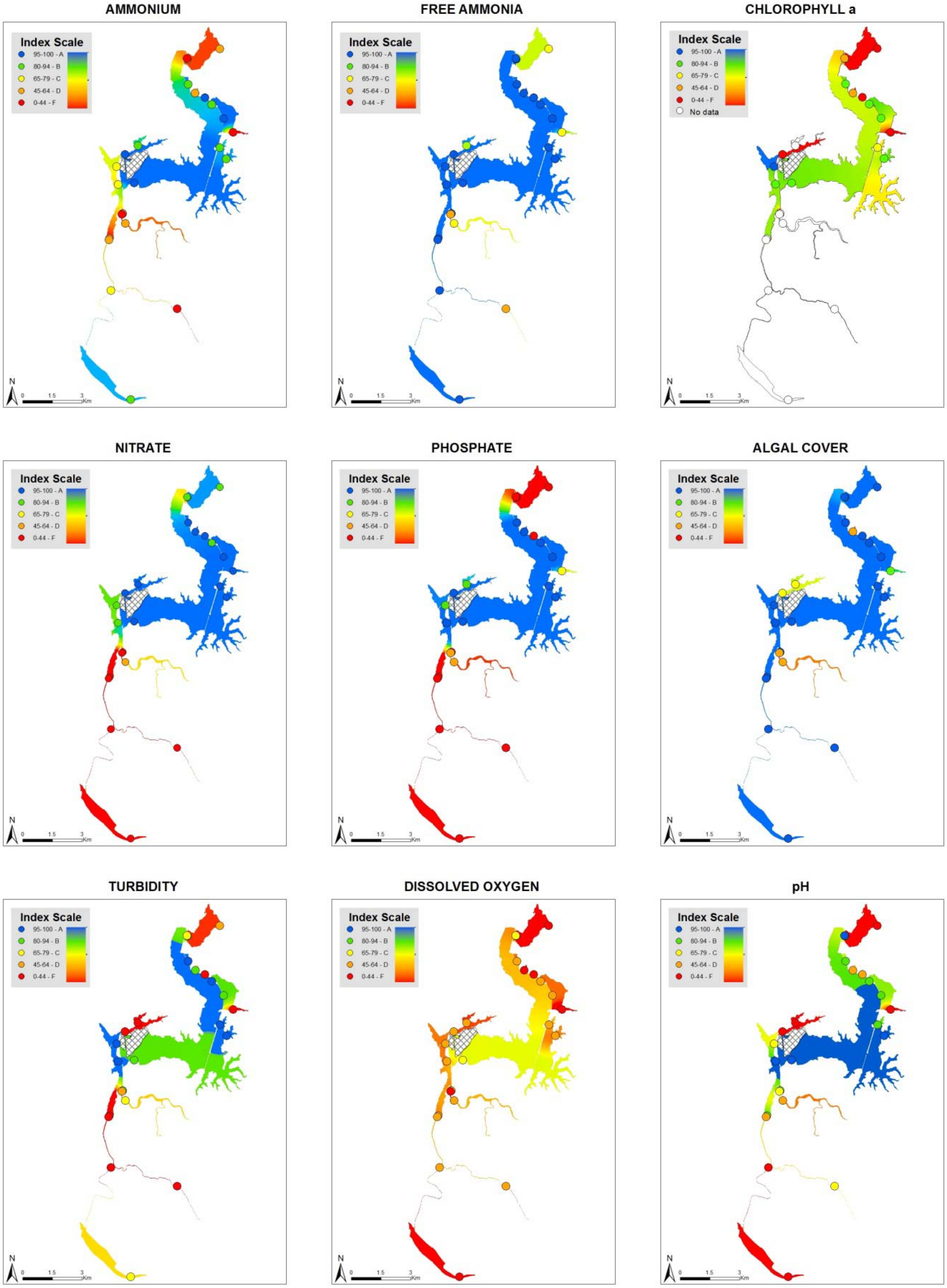


Figure 1. Spatial interpolation of parameter by parameter index values calculated using the Magnitude and Exceedance Quotient approach.

DISCUSSION

Our analysis suggested that there is variation in water quality conditions across Elkhorn Slough. In general, sites in the Lower Elkhorn Slough region have better water quality relative to Southern Estuary sites and those at the northernmost Upper Elkhorn Slough region. Based on the WQI approach more than half of our sampling sites (13/24) received failing grades and the highest grade was "B" which was assigned to only two sites. The majority of sites scoring lower grades or with poor water quality corresponded to those located behind water control structures that restrict tidal flow to arms of the estuary. On the contrary, better grades or good water quality were identified in sites close to the mouth or areas along the lower channel; this could be attributed to unrestricted tidal exchange and short residence time.

MEQ calculations supported WQI resultant values and allowed us to determine which parameters contributed to overall water quality conditions at each site. MEQ results indicated that nutrients (ammonium, nitrate and phosphate) and turbidity were the major drivers for poor water quality at the Southern Estuary sites. In particular, nitrate received the lowest scores, six out of the eight sites scored below eight. This could be explained by nutrient-rich runoff entering the wetlands from adjacent agricultural fields.

Examination of the results makes clear that the final WQI scores were lower than the average of all MEQ scores per site, because the scope calculation of WQI penalizes a site for ever falling below the target threshold for any parameter. The rationale for this lowering of scores below a simple average, as developed by the Canadian Council of Ministers of the Environment (CCME 2001) is that the thresholds have very real ecological consequences for organisms, so any instance in which values fall outside the threshold must be accounted for in the score. While a simple average is appropriate for a calculation such as an academic GPA, for water quality, it is important to be more conservative, and lower the score for a site where conditions ever fall outside thresholds considered appropriate for healthy ecology. In our case, we were relying on infrequent sampling – only monthly spot samples. A site where 11/12 monthly samples fall within the thresholds might have a relatively high average score. However, including scope in the calculation lowers the final grade for the site. This seems justified, since at one of our monthly checks conditions there were not healthy for estuarine inhabitants. Furthermore, given the rarity of our sampling, it seems likely that thresholds were exceeded more than once. The WQI method ensures that only sites that never fall outside thresholds set by the regulatory body will receive top grades, and this conservative approach seems justified, given the importance of water quality for estuarine organisms.

By using both scoring systems, we were able to provide an overall grade and identify which parameters were major influencing factors in poor water quality conditions. In order to improve water quality in areas with poor conditions some actions are required: reducing polluted run-off, restoring wetlands and improving management of water control structures. A recent study, indicated that water quality in areas with limited tidal flow can be improved by increasing tidal flushing even slightly (Hughes et.al 2011). Additionally, the restoration of wetlands will create more healthy marshes capable of taking up polluting nutrients and improving water quality. Finally, reducing polluted run-off into estuary's waters will also improve the quality of water; this can be achieved through the implementation of best management practices by farmers and converting farmlands to open space or restored wetlands.

Our report card provides a snap shot in time of water quality at 24 different sites within the Elkhorn Slough area. It is useful to evaluate spatial and temporal variation of water quality and to inform managers and restoration groups where to focus their efforts to achieve significant improvements in the quality of water. Furthermore, the expected annual updates of the report card will allow the identification of patterns and trends in water quality conditions, and serve as a metric to evaluate the effectiveness of current and future management actions.

Now that we have developed a method to summarize data analysis, future work should focus on conducting a time-series analysis to try to correlate changes in water quality to restoration projects implemented in the past two decades and to environmental changes. Although, this tool only provides a general overview on water quality issues at Elkhorn Slough, if used in combination with other environmental monitoring data it can help advance knowledge about the effect of water quality conditions on wildlife and habitats.

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Appendix I. Water Quality Index results for each sampling site.

Code	Name	Scope	Frequency	Amplitude	Index Value
Upper Elkhorn Slough					
1	Carneros Creek*	88.90	49.10	54.10	34
2	Blohm Porter Marsh*	88.90	34.60	25.80	43
3	Hudson Landing	66.70	22.20	49.10	51
4	Azevedo Pond, North*	44.40	10.30	3.20	74
5	Azevedo Pond, Central*	66.70	31.10	56.30	46
6	Azevedo Pond, South*	55.60	44.30	68.50	43
7	Kirby Park	55.60	10.30	6.00	67
8	Reserve North Marsh*	55.60	13.20	4.10	67
9	Strawberry Rd*	88.90	46.70	90.50	22
Lower Elkhorn Slough					
10	Whistle Stop	44.40	11.30	6.10	73
11	South Marsh	33.30	10.30	2.70	80
12	Vierra	33.30	5.60	1.50	80
13	Skipper's Landing	44.40	16.80	4.30	72
Bennett Slough					
14	Bennett Slough, West*	55.60	18.50	4.20	66
15	Bennett Slough, East*	55.60	44.40	50.10	50
16	Struve Pond*	87.50	36.40	28.10	43
Southern Estuary					
17	Moss Landing Road, North	75.00	36.40	48.10	44
18	Moss Landing Road, South*	100.00	52.30	58.30	27
19	Moro Cojo Slough*	100.00	44.30	42.10	32
20	Potrero Road, North	75.00	52.30	69.40	34
21	Potrero Road, South*	75.00	55.20	77.30	30
22	Monterey Dunes Way*	75.00	53.80	61.10	36
23	Tembladero Slough*	87.50	58.60	87.70	21
24	Salinas River Bridge*	75.00	48.80	61.80	37

*Sites behind water control structure