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Linking Land Cover and Water Quality in Elkhorn Slough

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AUTHOR AFFLIATION

The authors completed this report as graduate students at University of California Berkeley, throughout a semester-long course for the Data Science for the 21st Century fellowship program (DS421).

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.

Linking Land Cover and Water Quality in the Elkhorn Slough

Background

The Elkhorn Slough in Monterey County, California, is a hub for biodiversity. Home to the highest density of southern sea otters on the California coast (Eby et al., 2017), Elkhorn Slough provides habitat to hundreds of aquatic and terrestrial species, as well as recreational tourism and kayaking (Jeppesen et al, 2018). However, the past 70 years have brought a legacy of nutrient deposition, and the Elkhorn Slough now has some of the highest dissolved nutrient concentrations of estuaries in the U.S. (Tetra Tech, 2018). Elevated nutrient concentrations are attributed to nutrient application and runoff from specialty agricultural crops surrounding the Slough, and the effects of these nutrients are exacerbated in wetlands with dikes, tide gates, and culverts where flushing is limited and residence time is high (Hughes et al., 2011). In efforts to diminish deleterious effects of eutrophication on marine life such as sea otters, eelgrass beds, fish, and migratory birds in Elkhorn Slough, the Central Coast Regional Water Quality Board is setting Total Maximum Daily Load (TMDL) allocations for ammonia, chlorophyll a, floating algae, macroalgal cover, total nitrogen, dissolved oxygen, and phosphorus levels (Tetra Tech, 2018). Analyzing land cover change and its impacts on nutrient loading in the Elkhorn Slough may help inform the TMDL process, as well as shed light on how restoration or fallowing of surrounding agricultural land can potentially reduce nutrient loading in the Slough.

Objective

The main objective of our proposed project involved correlating seasonal nutrient data to surrounding land cover classifications. Using classified land cover classifications and in situ water quality data, we assessed how surrounding land cover, with particular attention to crop type, impacts nutrient influx in the Slough.

Research Questions

1. What are the major land cover types within four tidally-restricted sub-basins of the Elkhorn Slough (East Bennet, North Marsh, North Azevedo, and Moro Cojo) from 2007 to 2018, and how does percent land cover change throughout this time period?
2. What are the correlations among the Slough's 30 year water quality data (with particular attention to nitrates and phosphates in East Bennet, North Marsh, North Azevedo, and Moro Cojo), land cover, and local weather from 2007 to 2018?

Data

Source	Data	Use
Elkhorn Slough	**In Situ Water Quality (1990-2018):** Ammonia, algal cover, chlorophyll a, nitrate, orthophosphates, turbidity, dissolved oxygen, pH, salinity, temperature	Time Series Analysis & Correlation to Land Cover Type
Elkhorn Slough	**Weather:** Air temperature, relative humidity, total photosynthetically active radiation, cumulative precipitation, wind speed, wind direction	Correlation to Nutrient Spikes
CropScape	**Agricultural Classification (2007-2018):** 30-meter resolution annual data	Land cover Classifications & Correlation to Nutrient Spikes

Methods

To identify land cover change in Elkhorn Slough, we downloaded geotiff files from CropScape (https://nassgeodata.gmu.edu/CropScape/) from 2007 to 2018 to acquire annually classified land cover data for our study site (Fig. 1). We then clipped each CropScape raster to four watershed sub-basins ("watersheds.zip" shapefiles: https://www.elkhornslough.org/research-program/mapping-gis/) that included our sites of interest (East Bennet, North Marsh, North Azevedo, and Moro Cojo) (Fig. 2). Next, we aggregated our land cover data per watershed sub-basin into functionally relevant categories that include: Developed, Field Crops, Forest/Shrubland, Fruits and Vegetable Crops, Grass/Open Space, Strawberries, Tree Crops, and Wetlands (Fig. 3). We did not include Open Water in our land cover percent calculations, although we do represent this class in our output maps. We then correlated these land cover classes to nutrient data, and also correlated precipitation events to our aggregated nutrient data. For these analyses, each replicate was a site-month: the value for a single site in a single month. For land cover data, values were identical for all 12 months of the year, because the analysis was conducted at an annual time scale. Finally, we created an R Shiny web app that displays the land cover map per year and associated nutrient and precipitation data for each of the four watershed sub-basins.

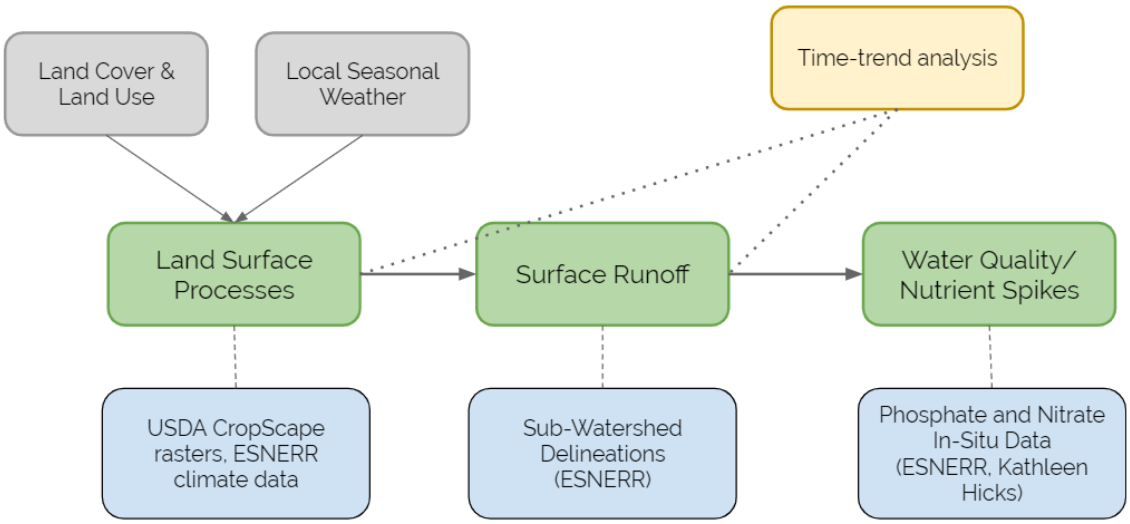

Figure 1. Conceptual model of the methodology including land cover classifications and nutrient analysis.

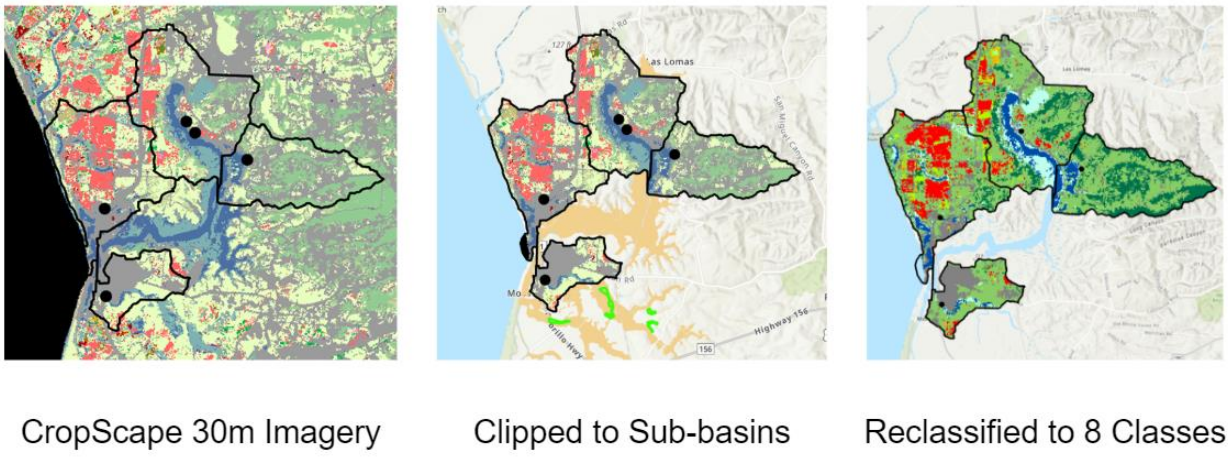

Figure 2. Example of the methodology of downloading 2014 CropScape imagery, clipping it to the four sub-basins, and reclassifying these raster files to specific land cover classes.

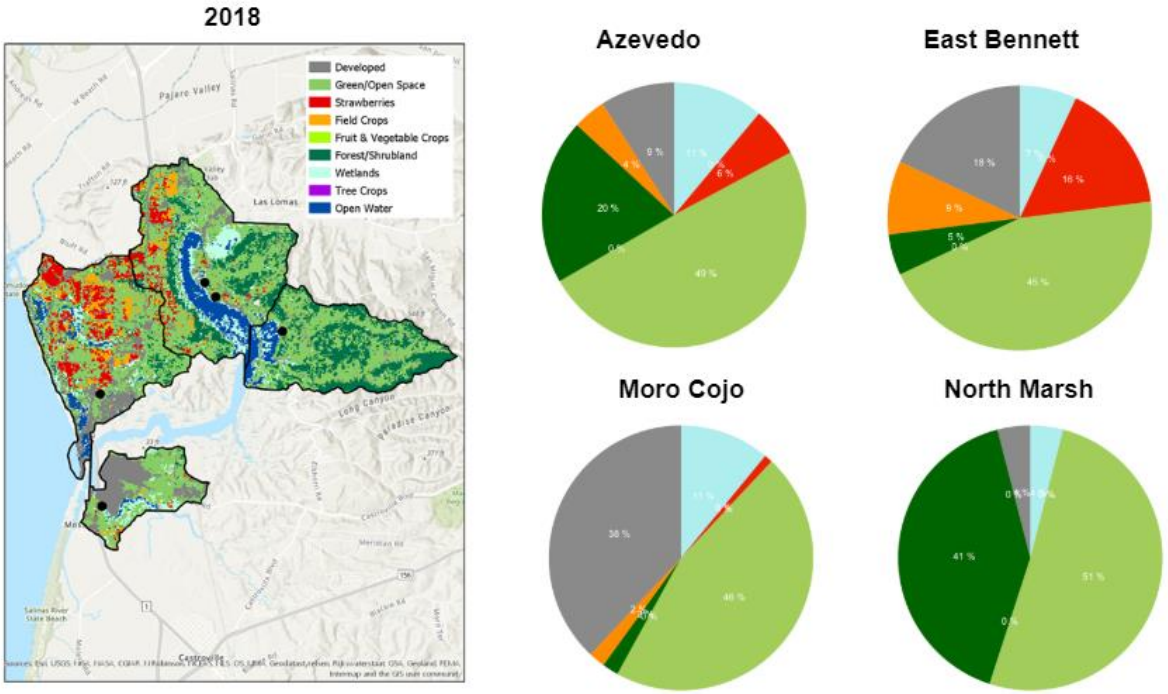

Figure 3. 2018 Land Cover Classifications and Percent Land Cover per Sub-basin, based on reclassified CropScape Data.

Results

The major land cover types within four tidally-restricted sub-basins of the Elkhorn Slough (East Bennett, North Marsh, North Azevedo, and Moro Cojo) from 2007 to 2018 include green/open space and forest/shrubland in North Marsh, developed and green/open space in Moro Cojo, strawberries, field crops, and green/open space in East Bennett, and green/open space, forest/shrubland, and wetland in Azevedo (Fig. 4).

Percent land cover changes throughout this time period by greater shifts in strawberry production in the East Bennett (specifically in 2007, 2009, 2014, 2017, and 2018) and Azevedo (2014, 2017, and 2018) sub-basins, a large and consistent percentage of development in the Moro Cojo sub-basin, and a slightly increased percentage of forest/shrubland in the North Marsh sub-basin starting in 2015 (Fig. 4). Across a majority of the sub-basins (all except North Marsh), the greatest years of strawberry production appeared to occur in 2009, 2014, 2017, and 2018, with 2007 also having large production in the East Bennett and Moro Cojo sub-basins. Additionally, field crops appeared to have high production in 2010 for all four sub-basins.

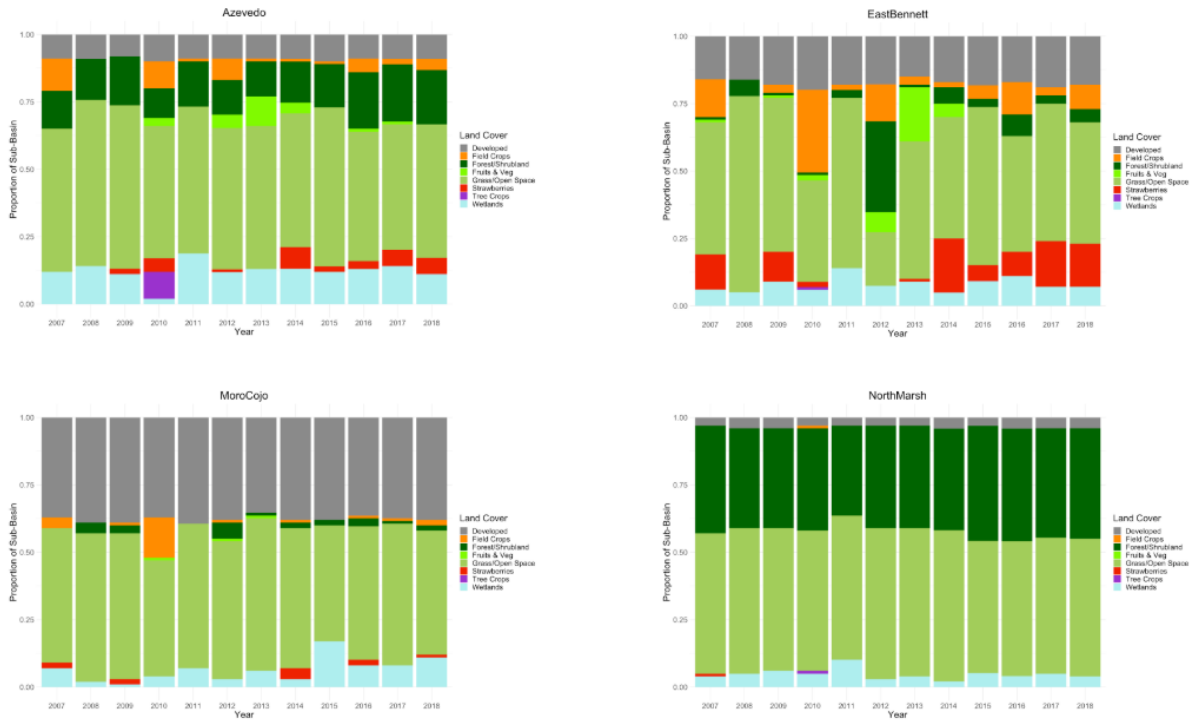

Figure 4. Percent change of land cover classes for each of the four sub-basins from 2007 to 2018.

We ran several regressions with the data collected, considering the impact of land use and precipitation on nutrient levels. Our preferred specification includes fixed effects for year and subbasin, which means that the variation driving the model is within sub-basin deviations from average annual trends in the Elkhorn Slough. The primary regression specification is:

$$Nutrient = Precip_t + LandUse_{it} + Basin_i + Year_t + \epsilon_{it}$$

where "Nutrient" is the level of one of our three nutrients of interest (Orthophosphate as P, Ammonia as N, and Nitrate as N), "Precip" is the monthly precipitation (basin-wide), "Land Use" is the annual total area of eight different land categories in each sub-basin, "Basin" is sub-basin fixed effects, and "Year" is an annual fixed effect. The regressions with Orthophosphate and Ammonia as dependent variables yielded no significant effects, except in the case of lagged monthly precipitation and land in strawberries on Orthophophate levels. In contrast, the regression with nitrate had several significant results, shown below.

Regression Results on Nitrate Levels in the Elkhorn Slough

	OLS FE Regression
Monthly Precipitation	0.0776 (0.0613)
Developed Land	0.0102* (0.00596)
Strawberries	-0.00703 (0.00595)
Field Crops	-0.0782* (0.0402)
Fruit and Vegetable Crops	-0.0744** (0.039)
Forest and Shrubland	0.0104* (0.00597)
Grassland and Open Space	-0.0105* (0.00587)
Tree Crops	2.432* (1.232)
Year FE	Yes
Sub-basin FE	Yes
Adjusted R Square	0.0723

In the above results, * reflects a p-value < 0.1, ** a p-value < 0.05, and *** a p-value < 0.01. We find that an increase in the area of land dedicated to tree crops, developed land, and forest/shrubland are linked to an increase in nitrate. In contrast, an increase in area in grassland/open space, fruit and vegetable crops, and field crops are linked with a reduction in nitrate levels. These results are robust to changes in the calculation of precipitation (lagged monthly precipitation, precipitation measured the day of sampling, or a dry/wet season indicator). Overall, however, these regressions are limited in their explanatory power for all of the nutrients of interest.

Next Steps & Limitations

The major limitation encountered in this project involved understanding the mechanisms of nutrient fluxes in the Slough, as various factors including upwelling, land cover processes, groundwater legacy inputs, and tidal restrictions play pivotal roles in nutrient deposition in this

estuary. Therefore, correlations between land cover classes and monthly nutrient levels do not imply causation. Future research could benefit from incorporating increased spatial resolution of remotely-sensed products (example: using Planet 3m or Sentinel-2A 10m imagery in addition to 30m CropScape data) for land cover classifications, verifying classifications using ground-truthed land cover maps, and incorporating groundwater nutrient influx data from in situ collection. Improving nutrient loading estimates such that they are site-specific, rather than averages by land-use type, would greatly improve the analysis. Additionally, in future work, the effects of restoration or fallowing of land on nutrient levels can be analyzed in the Moro Cojo sub-basin.

Conclusion

Resolving the issue of impaired water quality necessitates evaluating how surrounding land cover contributes to the influx of limiting nutrients. This analysis can help identify potential solutions to improving water quality in Elkhorn Slough, and can be incorporated into the consideration of land use change in the TMDL allocations. In our efforts to increase the ecological viability of this system, we hope this analysis will facilitate dialogue with local landowners to determine solutions that maximize benefits for all stakeholders.

R Shiny App

For Website: The R Shiny App is hosted on a server here.

Backend: The R Shiny App can be downloaded, run, and edited from this GitHub repository.

References

Eby, Ron et al. “Serendipity in a salt marsh: Detecting frequent sea otter haul outs in a marsh ecosystem.” *Ecology* 98 (2017): 1-3.

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