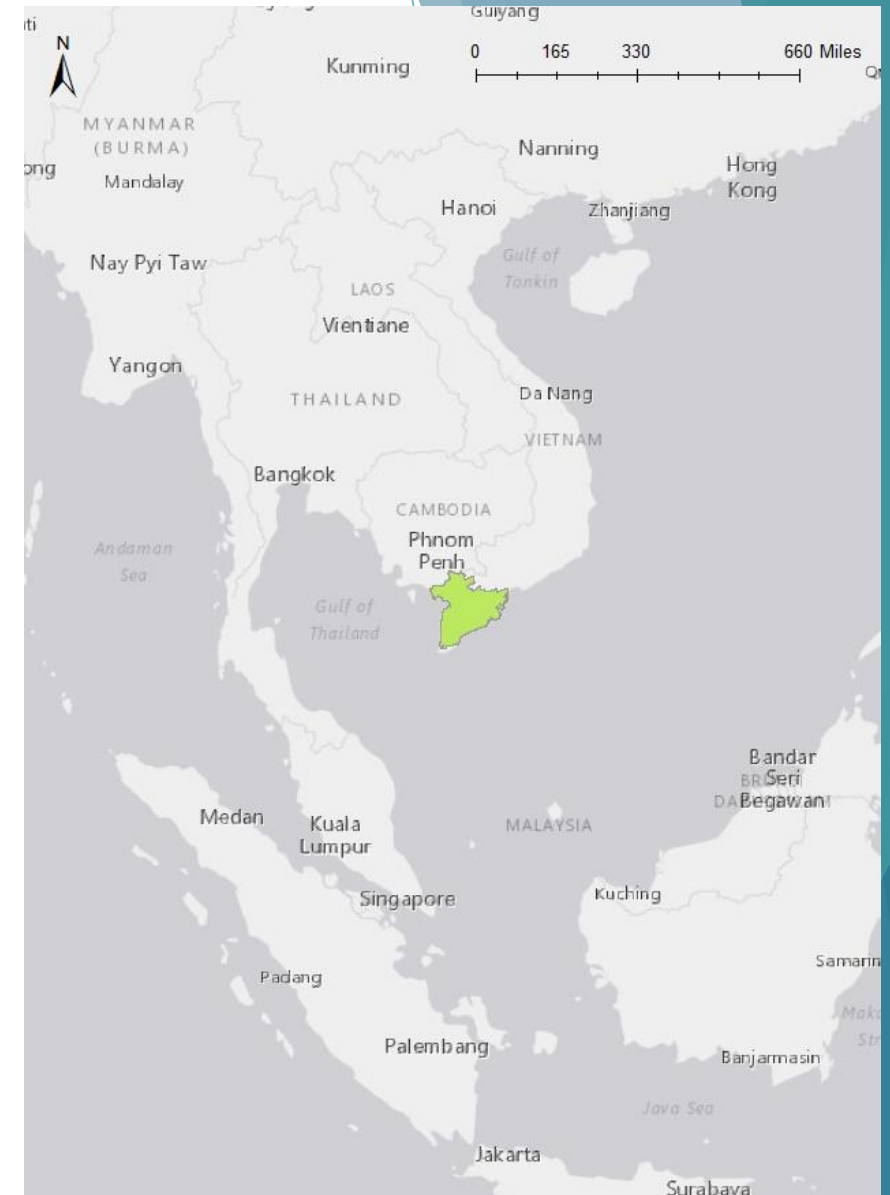


# Evaluation of Remote Sensing Methods as Proxy for Salinity Measurements in the Lower Mekong Delta

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# Saltwater Intrusion:

- ▶ Vietnam Delta major agricultural region
- ▶ 2015-2016 dry season was a record breaking drought year in Vietnam
- ▶ Salinity intrusion started 2 months earlier and extended further upstream than before, up to 50 km in some places
- ▶ Some mitigation practices include sluices and dykes, planting more salinity and drought resistant crops, combination pond/fields
- ▶ Need for better early warning system and water management



# Background & relevant studies:

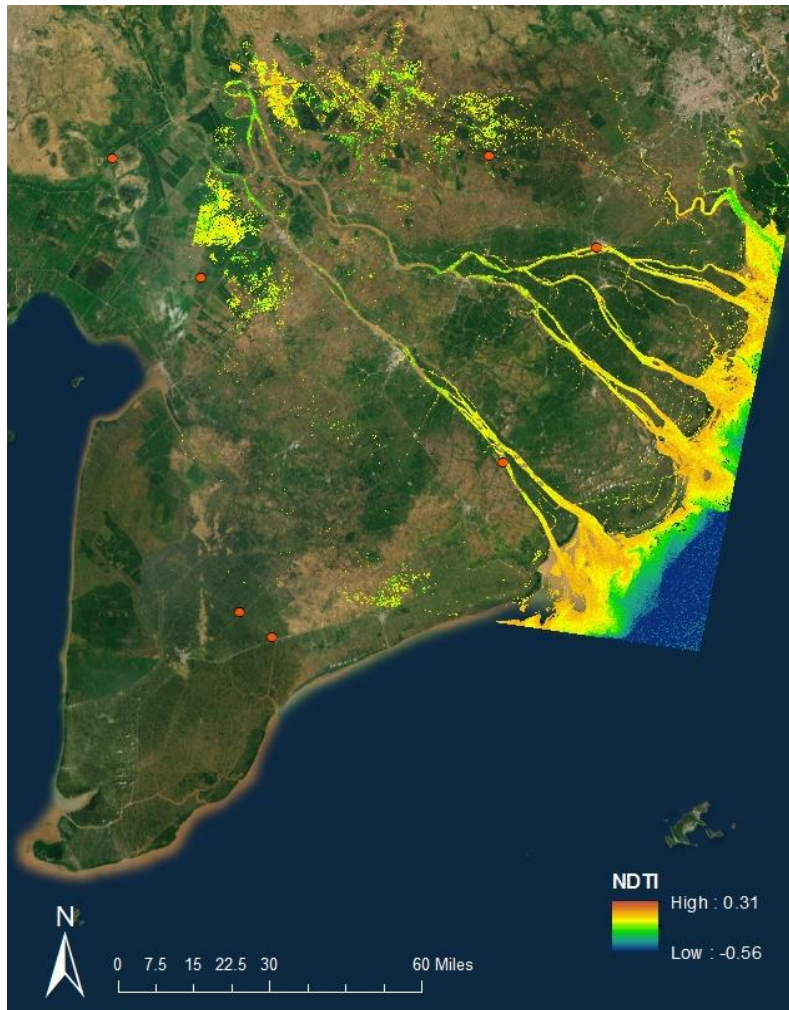
- ▶ Major motivation from Mekong needs assessment
- ▶ SMOS and SMAP measure ocean salinity
- ▶ In general, inverse relationship between CDOM and salinity in bays, estuaries, and lakes
- ▶ Keith et al. (2016) used MODIS and HICO to create CDOM and salinity algorithms for New England, Gulf of Mexico, and Mid-Atlantic
- ▶ Fang et al. (2007) performed similar study in Pearl River Estuary, China



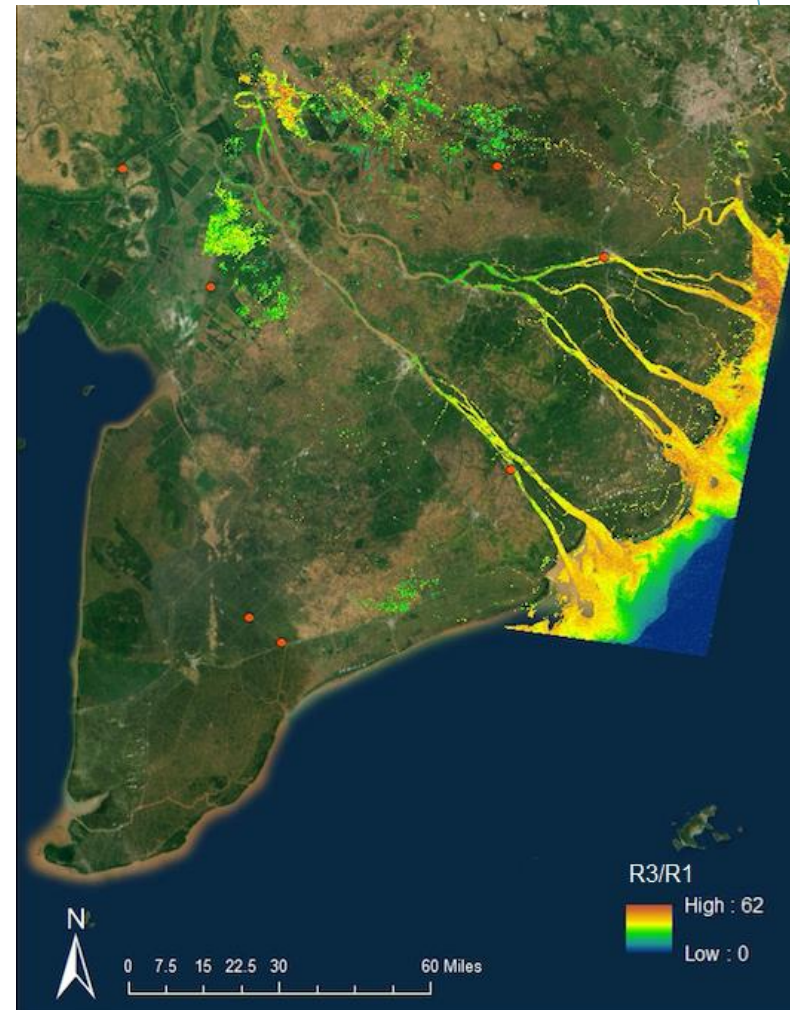
Open Access image from Wikimedia Commons:  
<https://commons.wikimedia.org/w/index.php?search=rice+drought&title=Special:Search&go=Go&uselang=en&searchToken=6etruhbg7kvf0cxc3iv3hi226>



# Viewing NDTI:



# and band ratio:



# Optical Satellite Imagery:

- ▶ Landsat 5 TM
- ▶ Using Google Earth Engine (GEE)
  - ▶ Around 70 points corresponded with satellite pass-overs
  - ▶ Using GEE simple cloud score band, only 4 points contained pixels less than 50% likely to be a cloud
  - ▶ GEE = somewhat of a black box...
- ▶ Using USGS Earth Explorer
  - ▶ USGS Surface Reflectance product → already atmospherically corrected
  - ▶ Much larger dataset
  - ▶ Plus/minus 1 day from observations

# Image processing:

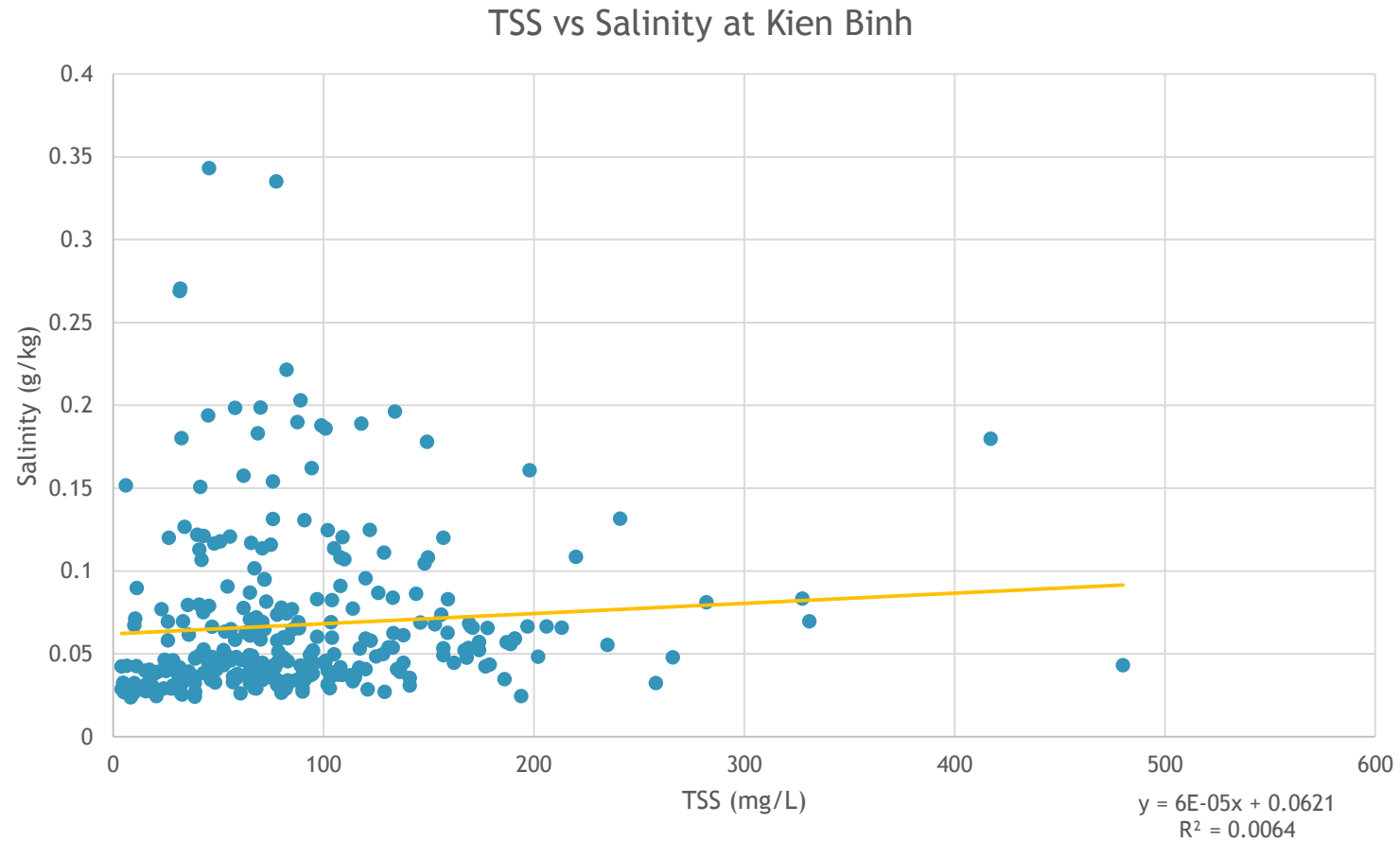
- ▶ Used cloud mask to remove clouds, cloud shadows, and land
- ▶ Calculated Normalized Difference Turbidity Index from Lacaux et al. (2007):
  - ▶ 
$$\text{NDTI} = \frac{(\text{Red} - \text{Green})}{(\text{Red} + \text{Green})}$$
- ▶ Calculated band ratio between red and blue bands

# In-situ Data:

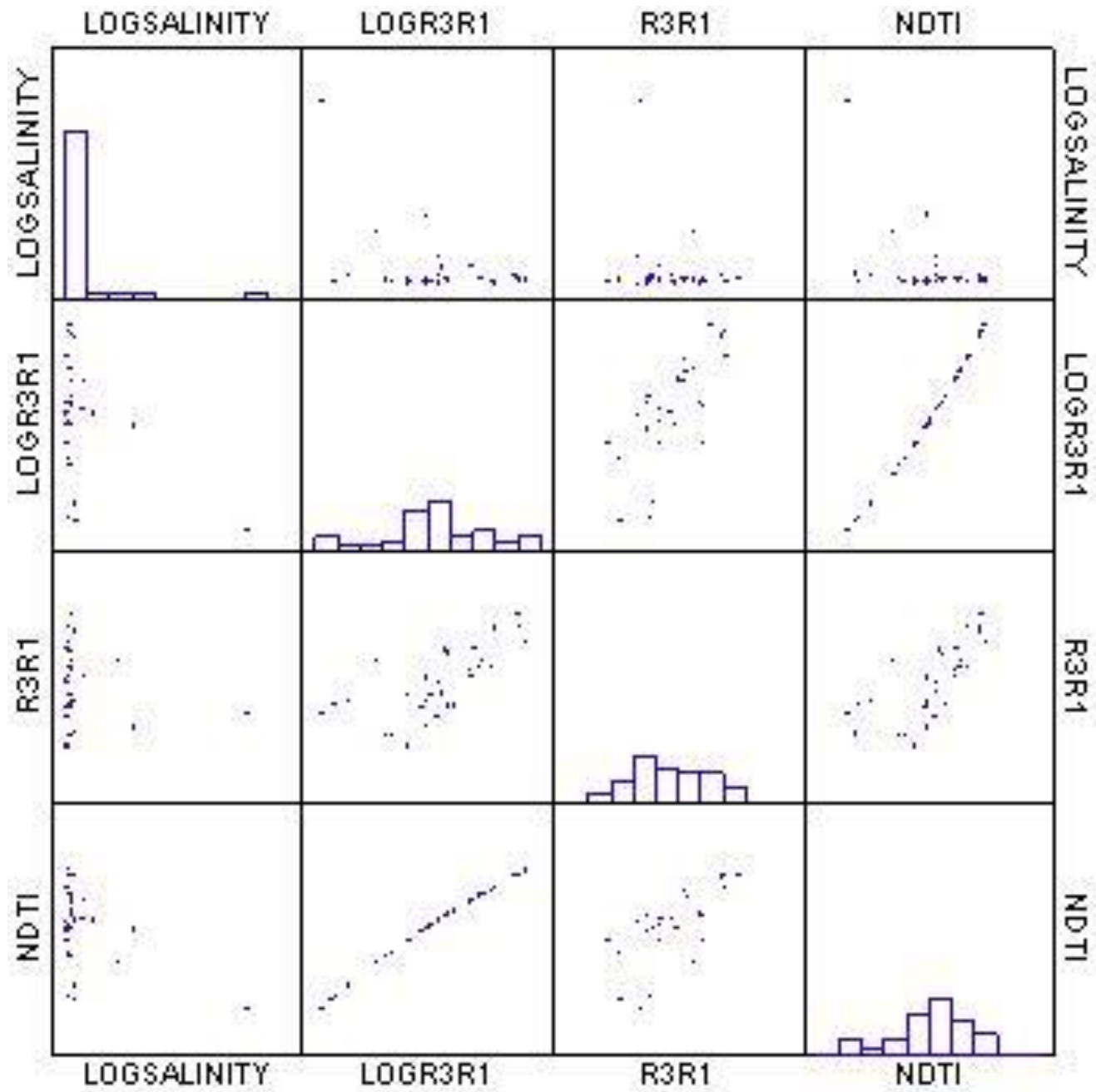
- ▶ Mekong River Commission: 48 permanent water quality monitoring stations
  - ▶ Focused on 7 stations Mekong Delta due to data sensitivity to location
  - ▶ Measurements taken “of surface water are taken from the river mid-stream every two months” or less
  - ▶ Evaluated in a lab
- ▶ Most have observations over 3 decades; many parameters
  - ▶ Used practical salinity units to combine parameters
  - ▶ Convert from milli-equivalents/liter to g/kg



# In-situ TSS vs Salinity:



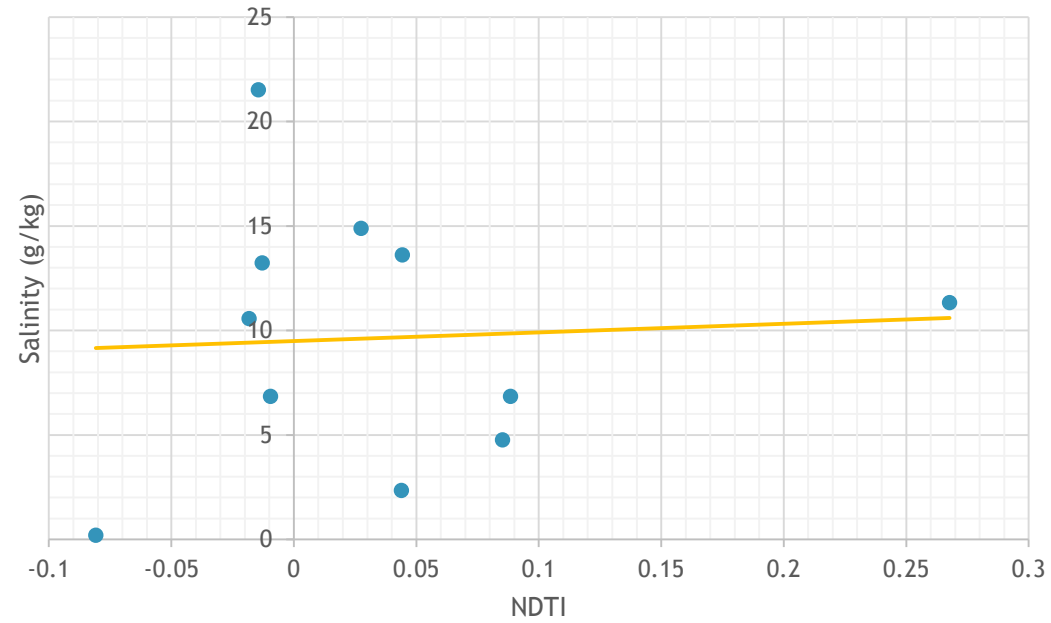






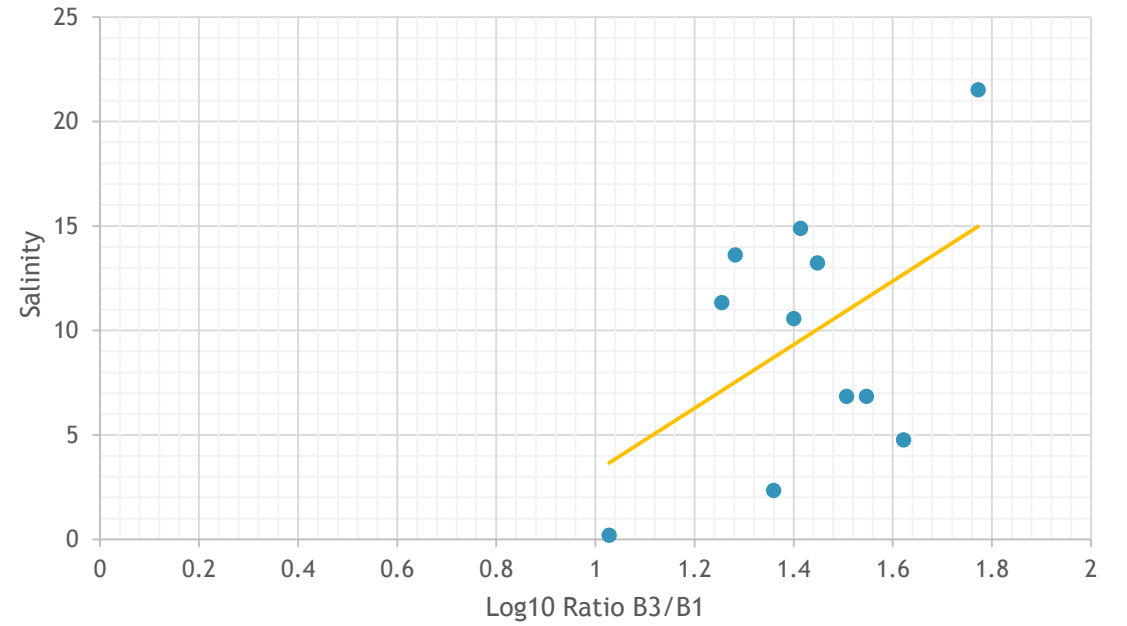
Chu Chi & Ho Phong  
Salinity vs NDTI

$$y = 4.1168x + 9.4937$$
$$R^2 = 0.0037$$



Chu Chi & Ho Phong  
Salinity vs Log R3/R1

$$y = 15.193x - 11.943$$
$$R^2 = 0.2371$$



# R3/R1 OLS for lower salinity stations:

## SUMMARY OUTPUT

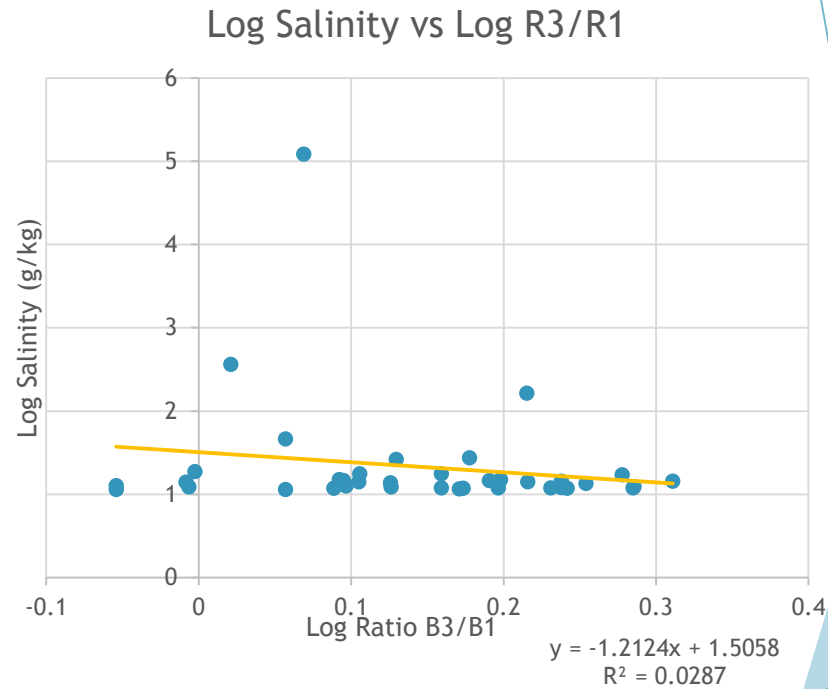
Regression Statistics					
Multiple R	0.169439716				
R Square	0.028709817				
Adjusted R Square	0.000958669				
Standard Error	0.704894074				
Observations	37				

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	0.51404033	0.51404033	1.034545211	0.316073326
Residual	35	17.39064793	0.496875655		
Total	36	17.90468826			

	Coefficients	Standard Error	t Stat	P-value
Intercept	1.505800313	0.205322186	7.333841231	1.42405E-08
X Variable 1	-1.212406412	1.191992402	-1.017125956	0.316073326



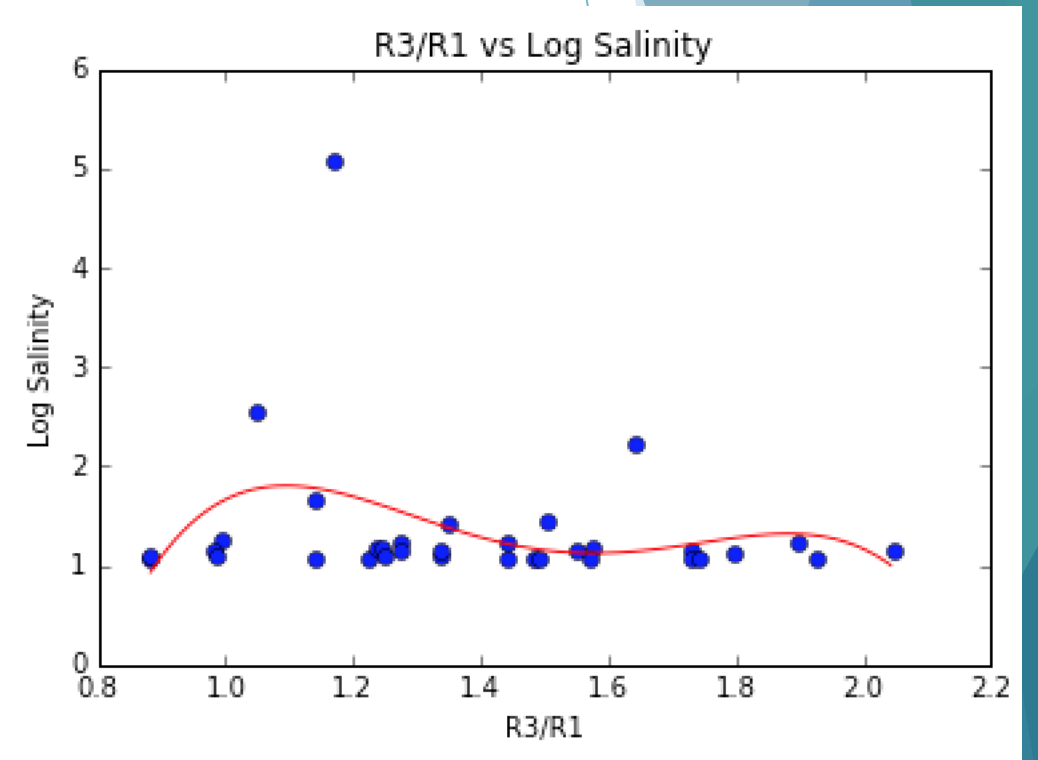
R3/R1 Polynomial regression:  $Y = -22.83x^4 + 136.77x^3 - 299.85x^2 - 284.02x - 96.21$

### Validation:

- ▶ Mean relative error: -36.43 %
- ▶ Root mean square error: 0.462 ppt
- ▶ Bias: -0.407

### Cross validation (k-fold, k=n):

- ▶ LOO cross validation mean relative error: -270.87 %
- ▶ LOO cross validation root mean square error: 0.804 ppt





# NDTI OLS for lower salinity stations:

## SUMMARY OUTPUT

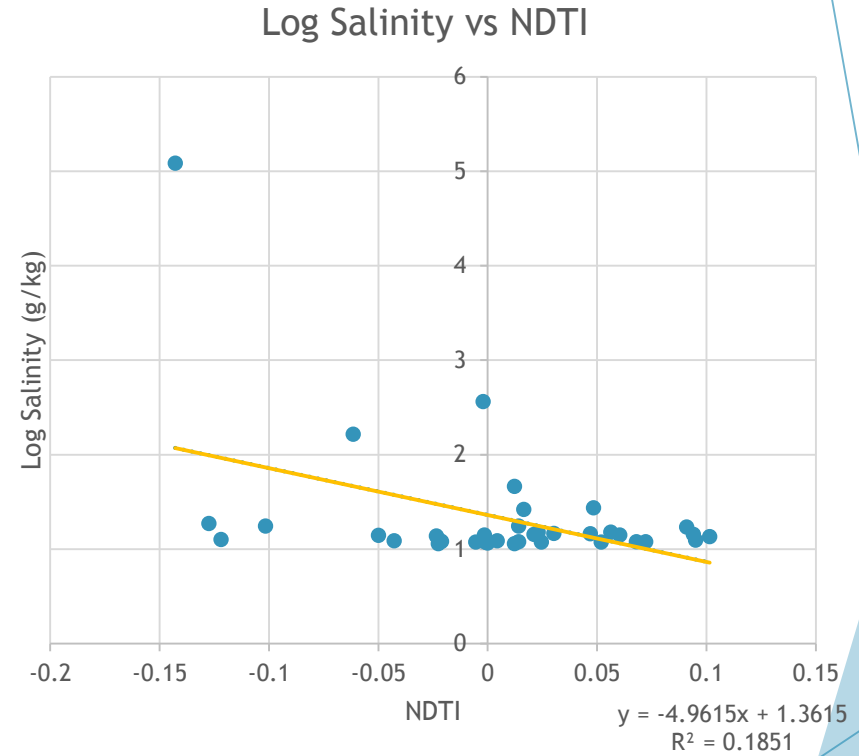
<i>Regression Statistics</i>	
Multiple R	0.430236184
R Square	0.185103174
Adjusted R Square	0.161820408
Standard Error	0.645655229
Observations	37

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	3.31421463	3.31421463	7.950222518	0.007862975
Residual	35	14.59047363	0.416870675		
Total	36	17.90468826			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	1.361549633	0.106613406	12.77090459	9.82655E-15
X Variable 1	-4.96150314	1.7596392	-2.819613895	0.007862975





# Caveats and discussion:

- ▶ Many hydrologic parameters that could affect salinity, especially where salinity is low:
  - ▶ streamflow, precipitation
  - ▶ storm surge, surface runoff
  - ▶ sedimentation, nutrient loading, irrigation practices
  - ▶ evaporation, surface temperature
  - ▶ channel type (natural vs canal)
- ▶ Each station could have its own algorithm
- ▶ Would like to have had data from last winter

# Conclusions:

- ▶ No significant correlation between R3/R1 ratio and salinity, or NDTI and salinity
- ▶ Many factors could be contributing to the local salinity levels
- ▶ Moving forward: will include Landsat 7 images, will look at relationship between other band combinations

# References:

- ▶ Fang, L. G., Chen, S. S., Li, D., & Li, H. L. (2009). Use of reflectance ratios as a proxy for coastal water constituent monitoring in the pearl river estuary. *Sensors*, 9(1), 656-673. <https://doi.org/10.3390/s90100656>
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- ▶ Kutser, T., Pierson, D., Tranvik, L., Reinart, A., Sobek, S., & Kallio, K. (2005). Using satellite remote sensing to estimate the colored dissolved organic matter absorption coefficient in lakes. *Remote Sens. Environ.*, 8(6), 709-720.
- ▶ Lacaux, J. P., Tourre, Y. M., Vignolles, C., Ndione, J. A., & Lafaye, M. (2007). Classification of ponds from high-spatial resolution remote sensing: Application to Rift Valley Fever epidemics in Senegal. *Remote Sensing of Environment*, 106(1), 66-74. <https://doi.org/10.1016/j.rse.2006.07.012>
- ▶ "Salinity Management Guide." *Salinity Management Guide: Learn about Salinity and Water Quality*. Water Reuse Foundation. Web. 28 Mar. 2017.