# Using ECOSTRESS to Monitor and Restore Delta Smelt Thermal Habitats

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## Introduction


- Climate change is warming water temperatures globally
- Warmer water threatens aquatic species longevity and survivability
- San Francisco Estuary and Sacramento-San Joaquin River Delta is home to the endangered Delta Smelt and their habitat is being negatively impacted by climate change[1]
- Preserving the Delta Smelt population is a major conservation challenge
- The "skin effect" is the difference between surface water temperature and water temperature at depth
- Conservation, targeted management, and restoration are important tools for maximizing beneficial uses and protecting habitat

## Objectives

1) To characterize the diurnal relationship between remotely sensed skin surface and in situ bulk water temperatures ("skin effect") in order to model a greater coverage of bulk water temperature for Delta Smelt thermal habitat conservation applications.
2) Assess and improve restoration and management actions impacts on habitat suitability in the Bay Delta through thermal remote sensing

## Methods

1) Developing the bulk water temperature harmonic regression model[3]
- Found the closest-in-time match between CDEC station measurement and ECOSTRESS overpass
- Calculated $R^2$ and the Root Mean Squared Error (RMSE) to quantify the skin effect (aka the relationship between the ECOSTRESS and CDEC measurements)
- Disaggregated the relationship by time of day (Pacific Standard Time):
  a. morning = 4 AM to 11 AM
  b. midday = 11 AM to 7 PM
  c. evening = 7 PM to 4 AM
- Used the summertime period to develop and evaluate the model (i.e., June to September) based on the established relationship between ECOSTRESS and bulk water temperature
- Harmonic Regression Model for bulk water temperature ($T_b$):

$$T_b = 3.755 + T_s * 0.839 + \sin(\pi * hour/12) * -0.071 + \cos(\pi * hour/12) * 0.785$$

With $T_s$ being the ECOSTRESS skin surface temperature and hour being the hour of the day

2) Applying the bulk water temperature harmonic regression model
- Calculated thermal habitat suitability maps using a binary "suitable" or "unsuitable" threshold at 25 degrees Celsius[2]
- Calculated the amount of area that was deemed suitable in each map as a percentage of the pixels

## References

1 Cloern, J. E., & Jassby, A. D. (2012). Drivers of change in estuarine-coastal ecosystems: Discoveries from four decades of study in San Francisco Bay. Reviews of Geophysics, 50 (4), 1–33. doi: 10.1029/2012RG000397
2 Brown, L. R., Komoroske, L. M., Wayne Wagner, R., Morgan-King, T., May, J. T., Connon, R. E., & Fangue, N. A. (2016). Coupled downscaled climate models and ecophysiological metrics forecast habitat compression for an endangered estuarine fish. PLoS ONE . doi: 10.1371/journal.pone.0146724
3 Gustine, R. N., Lee, C. M., Halverson, G. H., Acuna, S. C., Cawse-Nicholson, K. A., Hulley, G. C., & Hestir, E. L. (2021). Using ECOSTRESS to Observe and Model Diurnal Variability in Water Temperature Conditions in the San Francisco Estuary. IEEE Transactions on Geoscience and Remote Sensing, 1. doi:10.1109/TGRS.2021.3133411

## Data: ECOSTRESS & CDEC

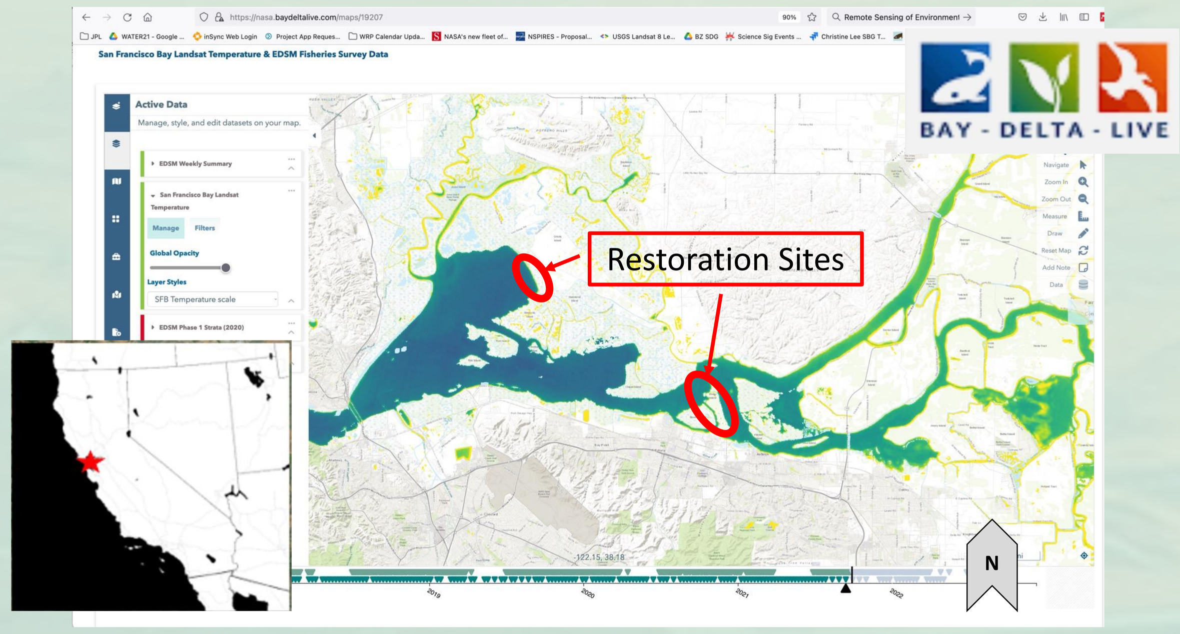
We utilize the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (**ECOSTRESS**) Land Surface Temperature and Emissivity product (L2) and the California Data Exchange Center (CDEC) in situ bulk water temperature measurements.

ECOSTRESS:
- ~70 m resolution & 1-5 day revisit cycle
- Used maps from July 2018 to September 2021

CDEC:
- Continuous monitoring every 15 minutes
- Use a record to match the ECOSTRESS record
- Used 4 stations: HON, FRK, GZB, GZL


## Study Basin

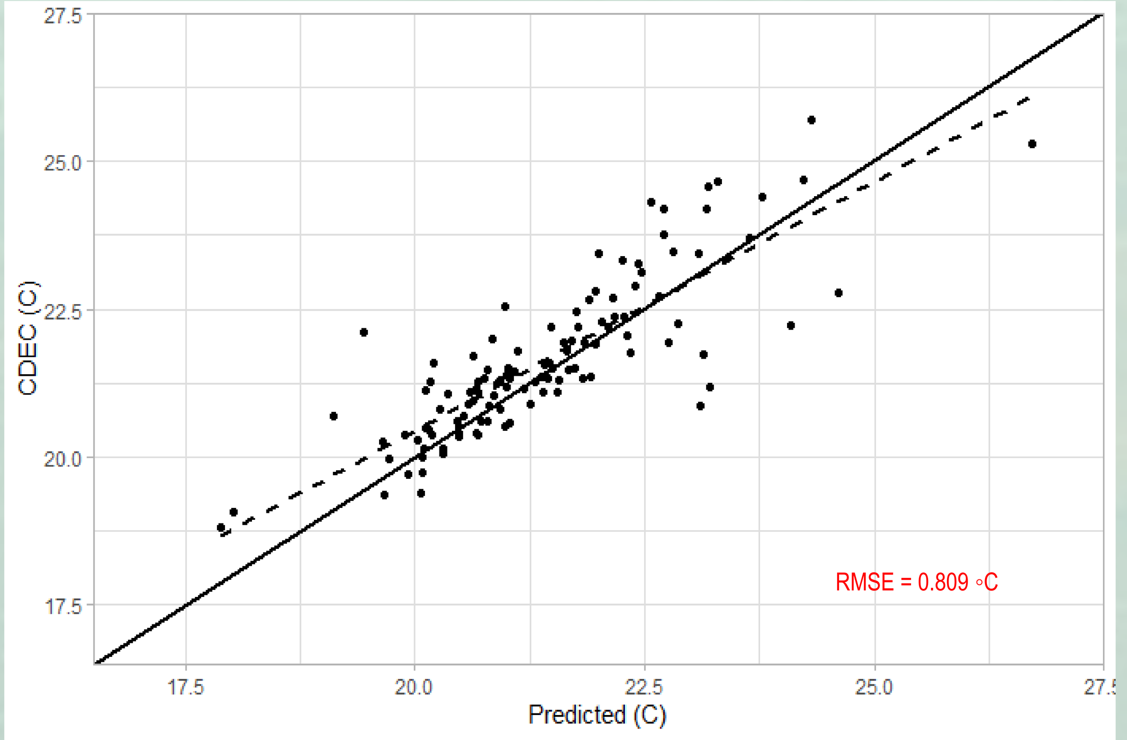
- San Francisco Estuary and Sacramento-San Joaquin River Delta ("Bay Delta")
- Delta Smelt habitat zone and biodiversity hot spot
- Highly complex and altered water system that drains most of the water from central and Northern California
- Many competing uses of the water: agriculture, in-stream uses, drinking water



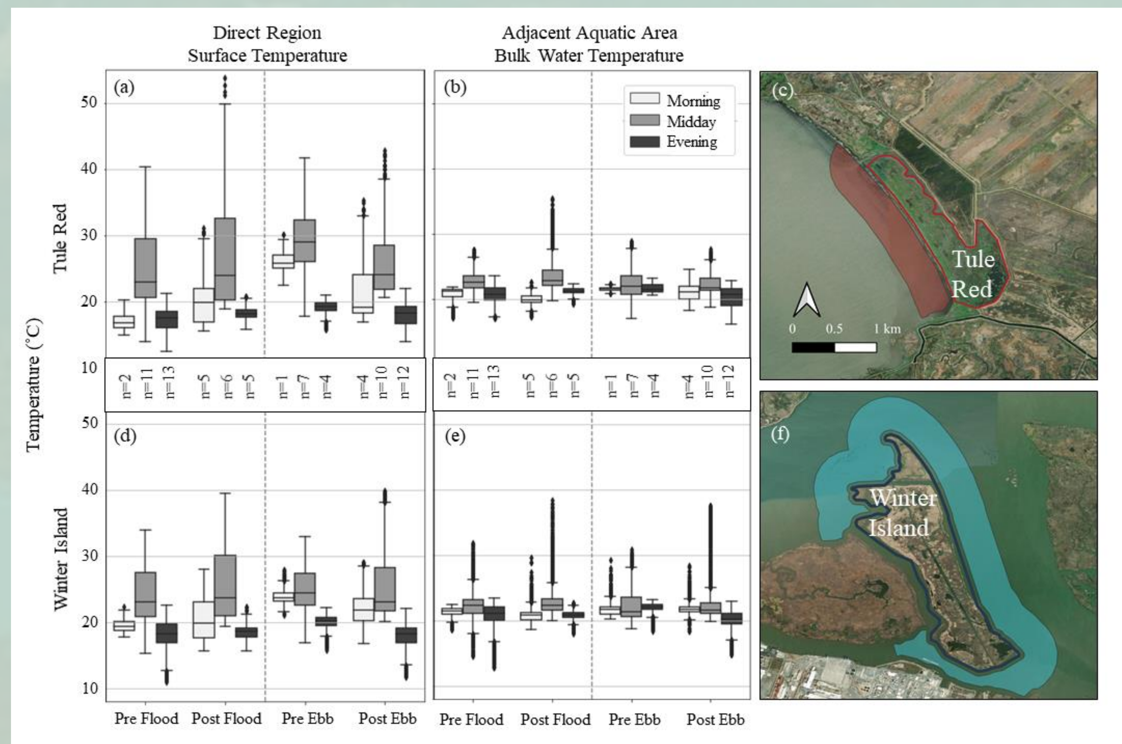

## Results: Model Development

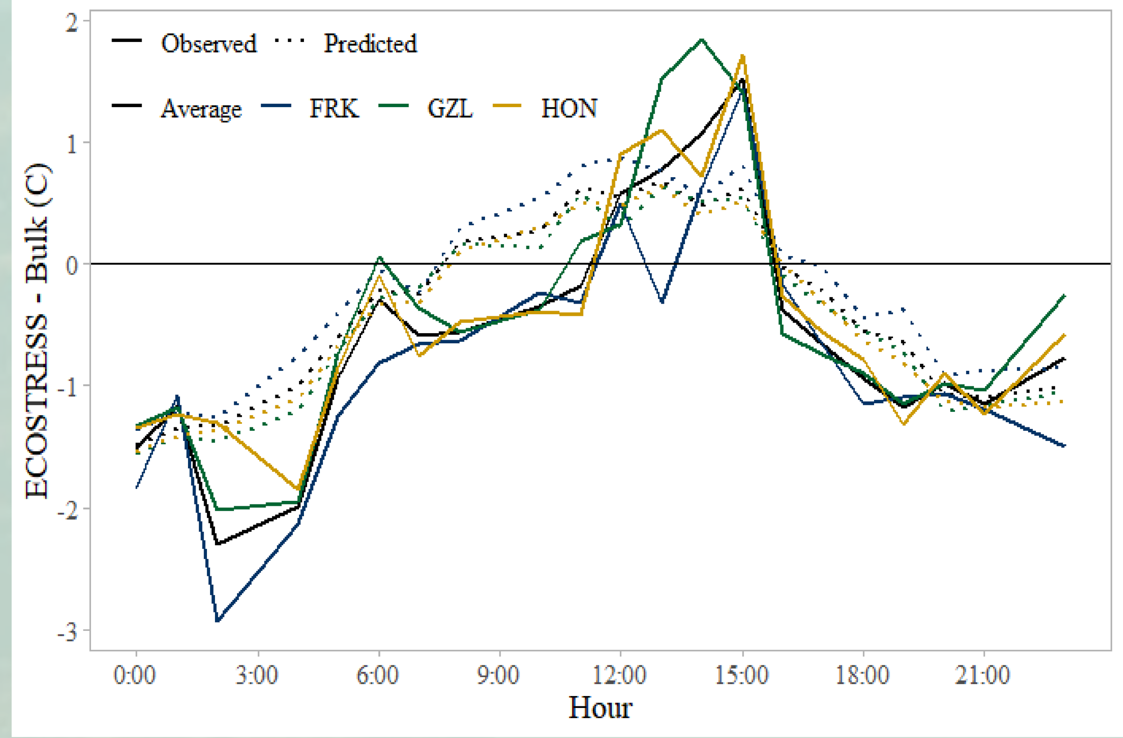
1) Quantifying the skin effect
- ECOSTRESS $T_s$ provides a reasonable proxy of in situ $T_b$
- Overall $T_s$-$T_b$ correlation is weaker than morning and evening correlations

2) Developing and evaluating the harmonic regression model
- Greatest difference between $T_s$ and $T_b$ around 2 pm and 6 PST
- Simple harmonic regression model performed as well as other physically-based models calibrated for the Bay Delta




*Below: Post tidal wetland restoration, $T_s$ in the regions decreased a median of 0.3 ºC for the Tule Red (decrease range: 0 – 6.8 ºC) and 0.8 ºC for Winter Island (range: 0 - 1.9 ºC). In a 500m buffer region, $T_b$ gave a median 0.3 ºC decrease for Tule Red (range: 0 - 1.4 ºC) and 0.2 ºC for Winter Island (range: 0 - 1.8 ºC).*




## Data Access

- With Bay Delta Live, data to be fully accessible for stakeholders (see Study Basin figure); BDL is fully funded by in region partners (CA, USGS, MWD, others) to provide geospatial webservices for decision support

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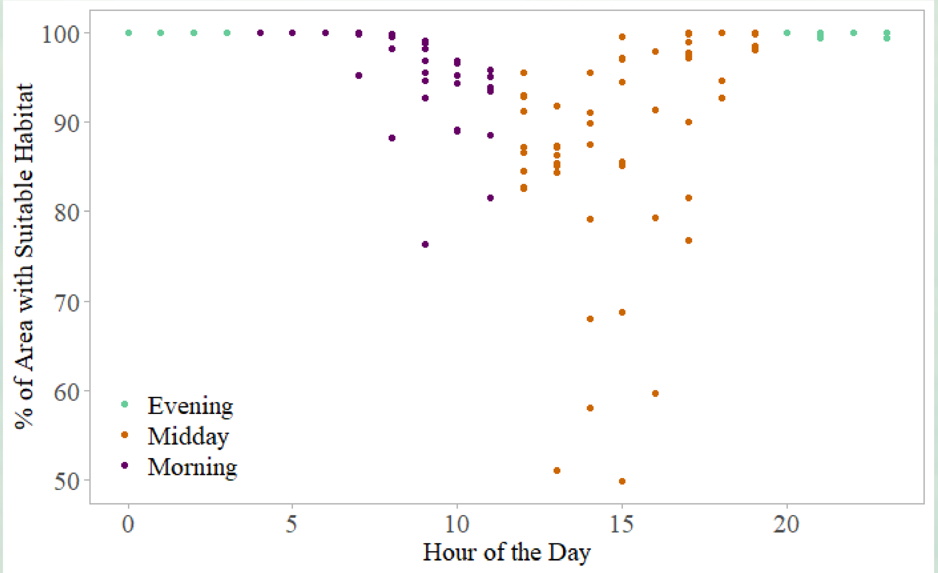
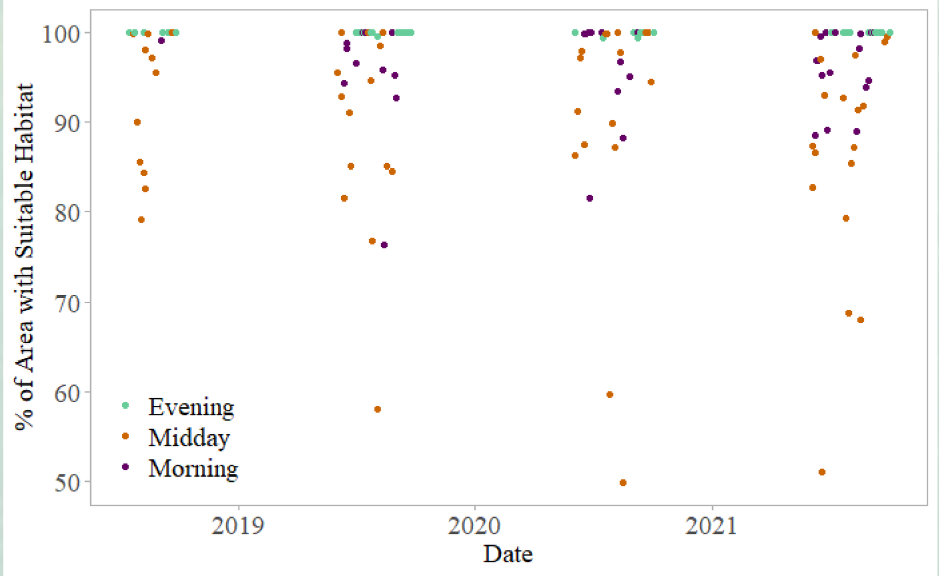
## Results: Applying the Model

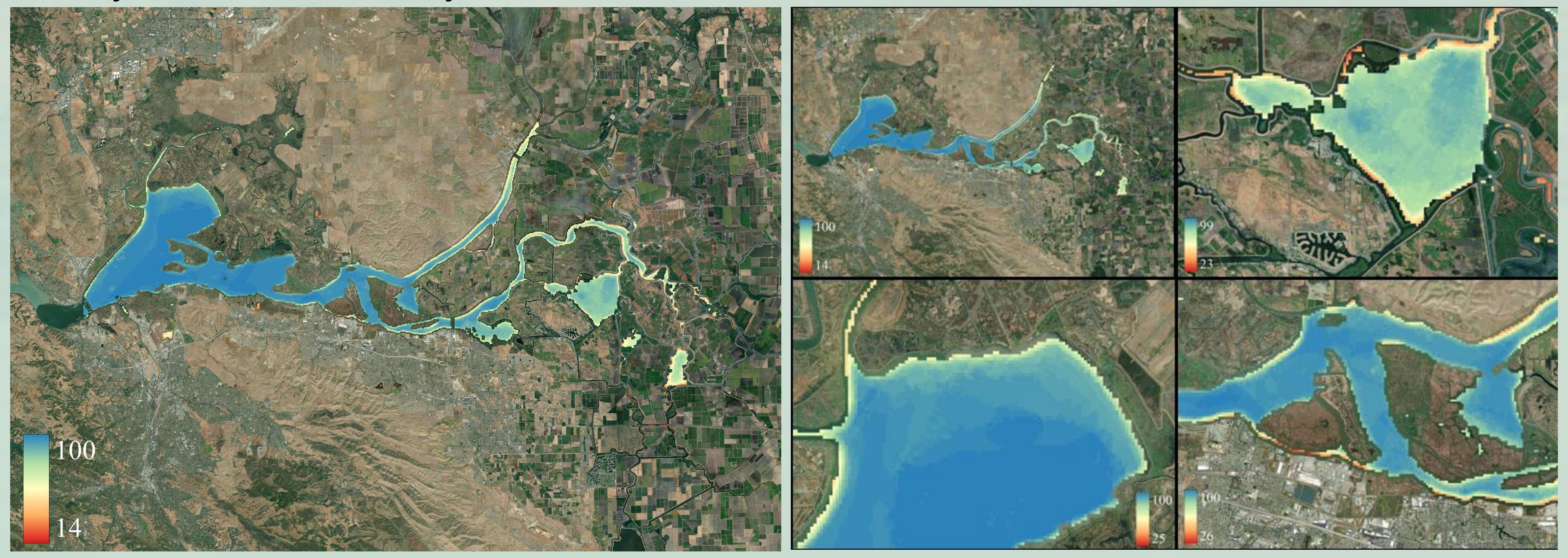
*Right: Percent of the Bay Delta study area that was deemed thermally suitable. Calculated for each of the ECOSTRESS maps in the record of interest. Evenings and the early morning hours are always thermally suitable, while the midday hours range between 100% and 50%.*




*Right: Percent of the Bay Delta study area that was deemed thermally suitable. Calculated for each of the ECOSTRESS maps in the record of interest. Midday hours during 2019 and 2020 had the least thermally suitable habitat over the whole record.*




*Below: frequency of thermal habitat suitability during the midday hours. Image on the left shows the whole bay delta and the grid of images on the right are areas within the bay delta that are key Delta Smelt habitat zones.*



## Conclusions

- ECOSTRESS provides unique diurnal coverage of the thermal conditions in the Bay Delta, showing distinct patterns in habitat suitability
- ECOSTRESS and remote sensing can be used to complement existing monitoring networks
- Increasing temperatures and droughts will have differential impacts across the Bay Delta landscape (and waterscapes)--remote sensing can help bridge gaps in measurements and sampling approaches to monitoring and managing this system