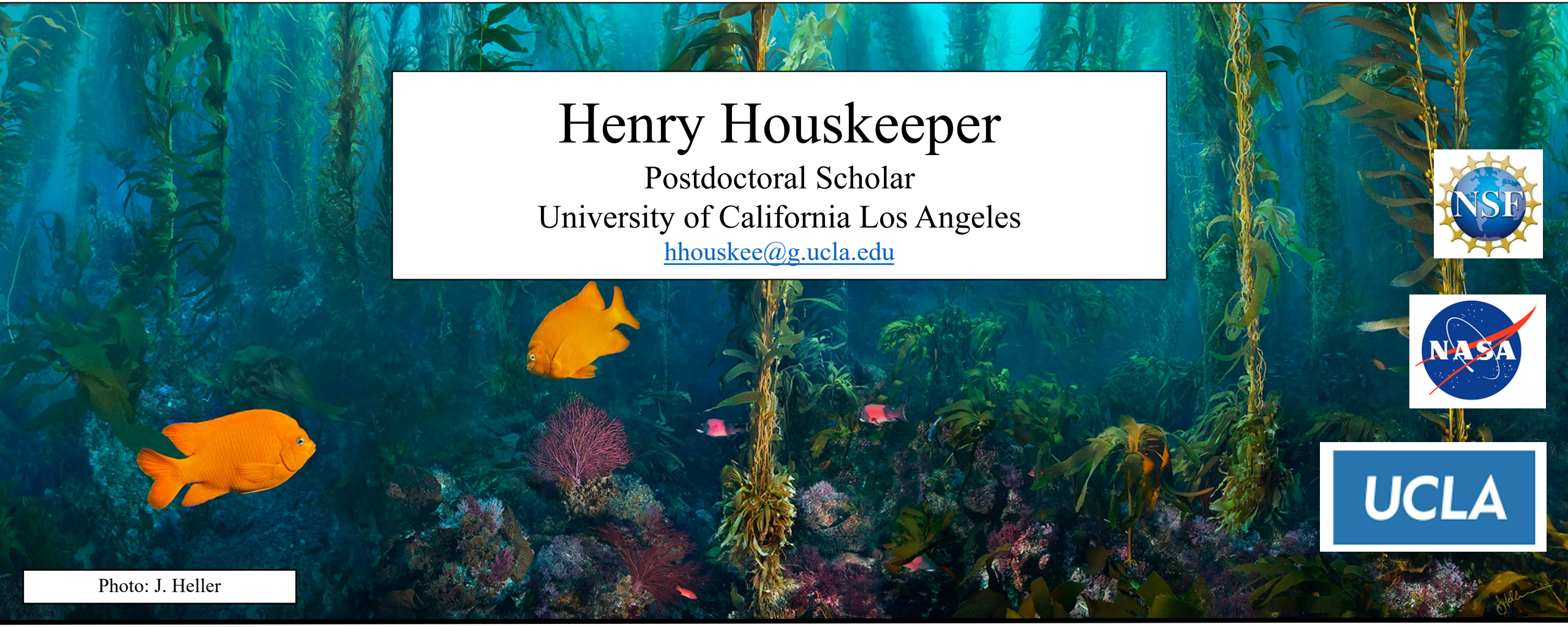
Scaling satellite observations of giant kelp forests for global-level analyses



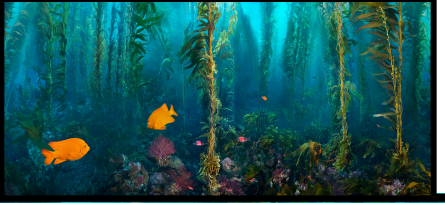
Henry Houskeeper

Postdoctoral Scholar

University of California Los Angeles

hhouskee@g.ucla.edu

Photo: J. Heller

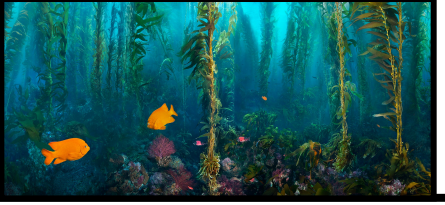


Remote monitoring of giant kelp forest ecosystems.

Outline

- Background
- Methods
  - Citizen Science
  - Spectral Unmixing
  - Artificial Intelligence
- Regional Results
  - Falkland Islands (Islas Malvinas)
  - U.S. West Coast and Baja California
- Next steps

Photo: J. Heller



Background - Importance

Kelp forests provide vertical structure that shapes productive and diverse coastal ecosystems around the globe.

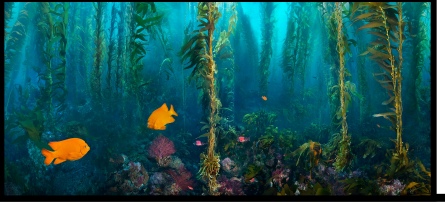
Source: Arafeh-Dalmau et al., (2020)

Canopy-forming kelps are foundation species

- Structure sub-tidal community.
- Provide food and shelter.

Sequester carbon.

Buffer coastlines from storm energy.



Background - Drivers

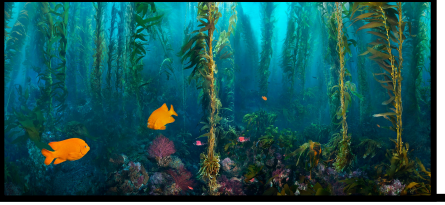
Kelp forests are regulated by bottom-up and top-down controls

Kelp growth requires cold, nutrient-rich, and clear water (plus exposed rocky substrate).

Grazers, especially sea urchins, can rapidly decimate a kelp forest.

In a healthy forest, the abundance of grazers is limited by predators (for US. West coast predators are namely sea otters and sea stars).

Severe kelp forests declines allow ecosystems to transition to a new stable state.

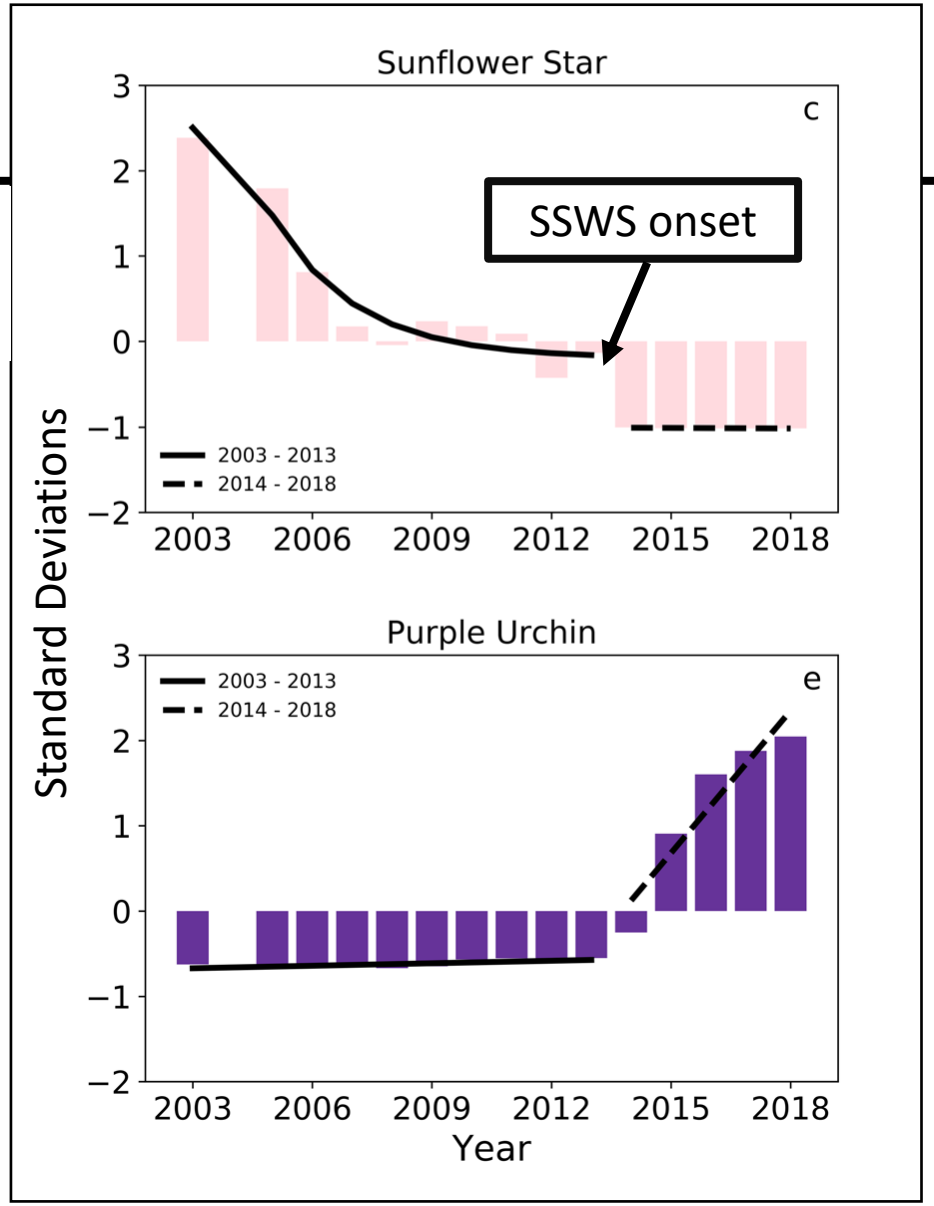


Background - Drivers

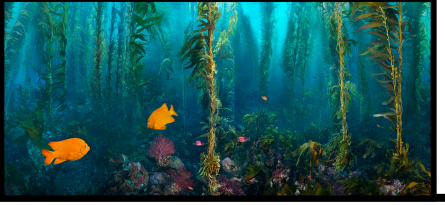
In 2013-2014, a severe Sea Star Wasting Syndrome (SSWS) event decimated west coast sea star populations.

Photo Credit: Multi-Agency Rocky Intertidal Network

New York Times

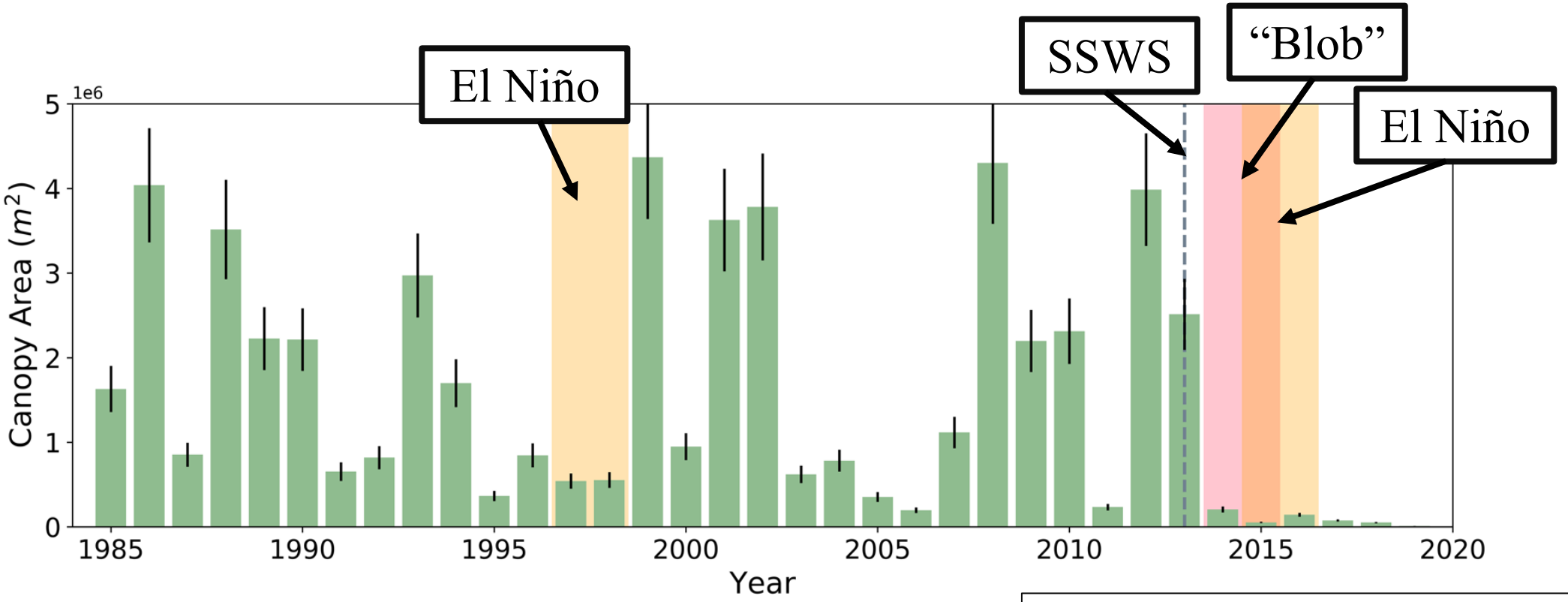


McPherson, Finger, Houskeeper, Bell, Carr, Rogers-Bennett, & Kudela (2020) *Communications Biology*.

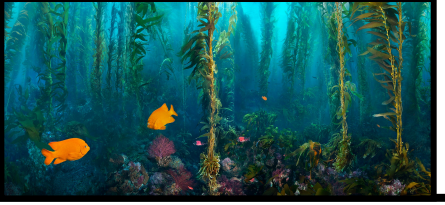


Background - Drivers

Kelp is resilient to individual stressors. Multiple stressors may push kelp past a tipping point.

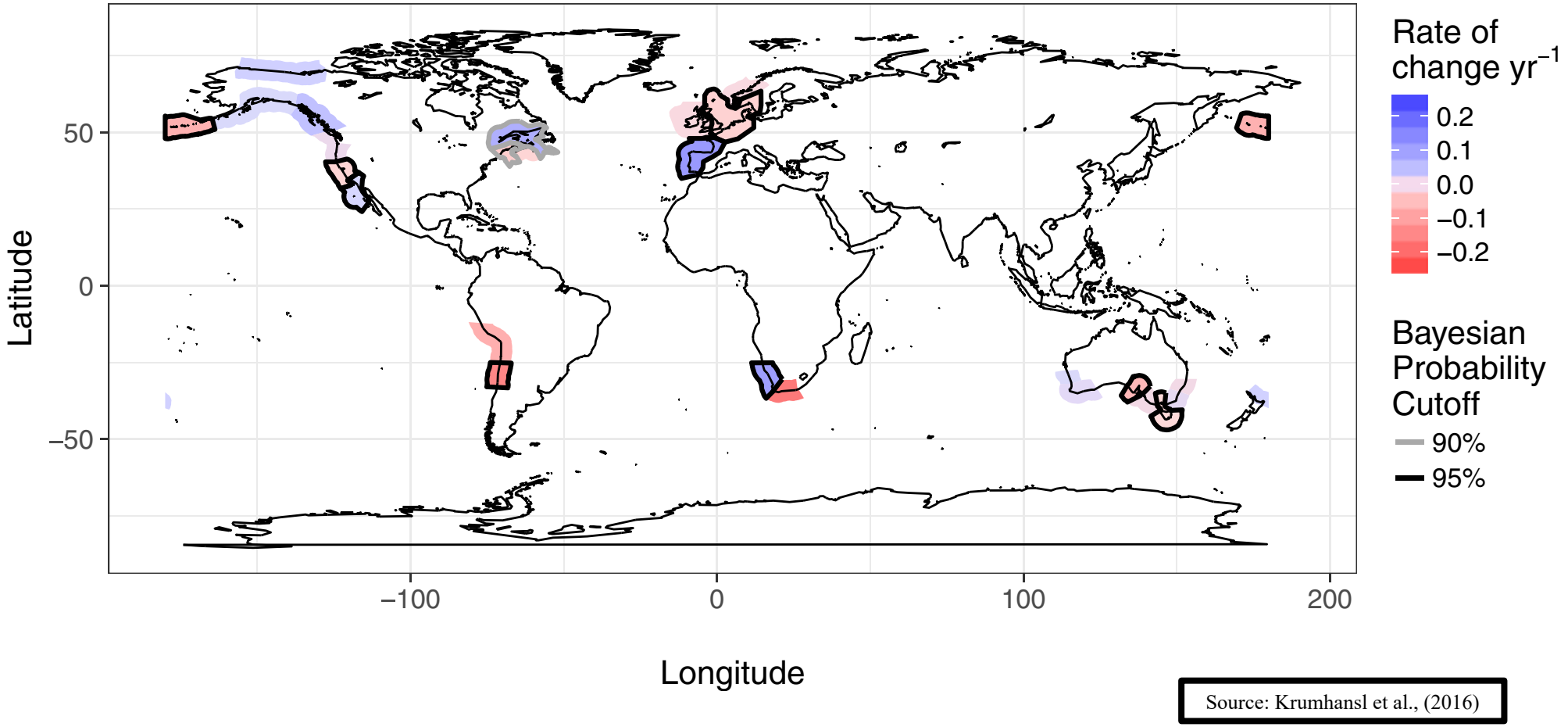


McPherson, Finger, Houskeeper, Bell, Carr, Rogers-Bennett, & Kudela (2020) *Communications Biology*.

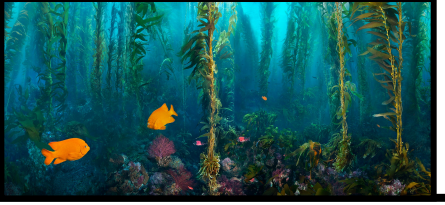


Background – Global Status

Global trends in kelp forest health are mixed

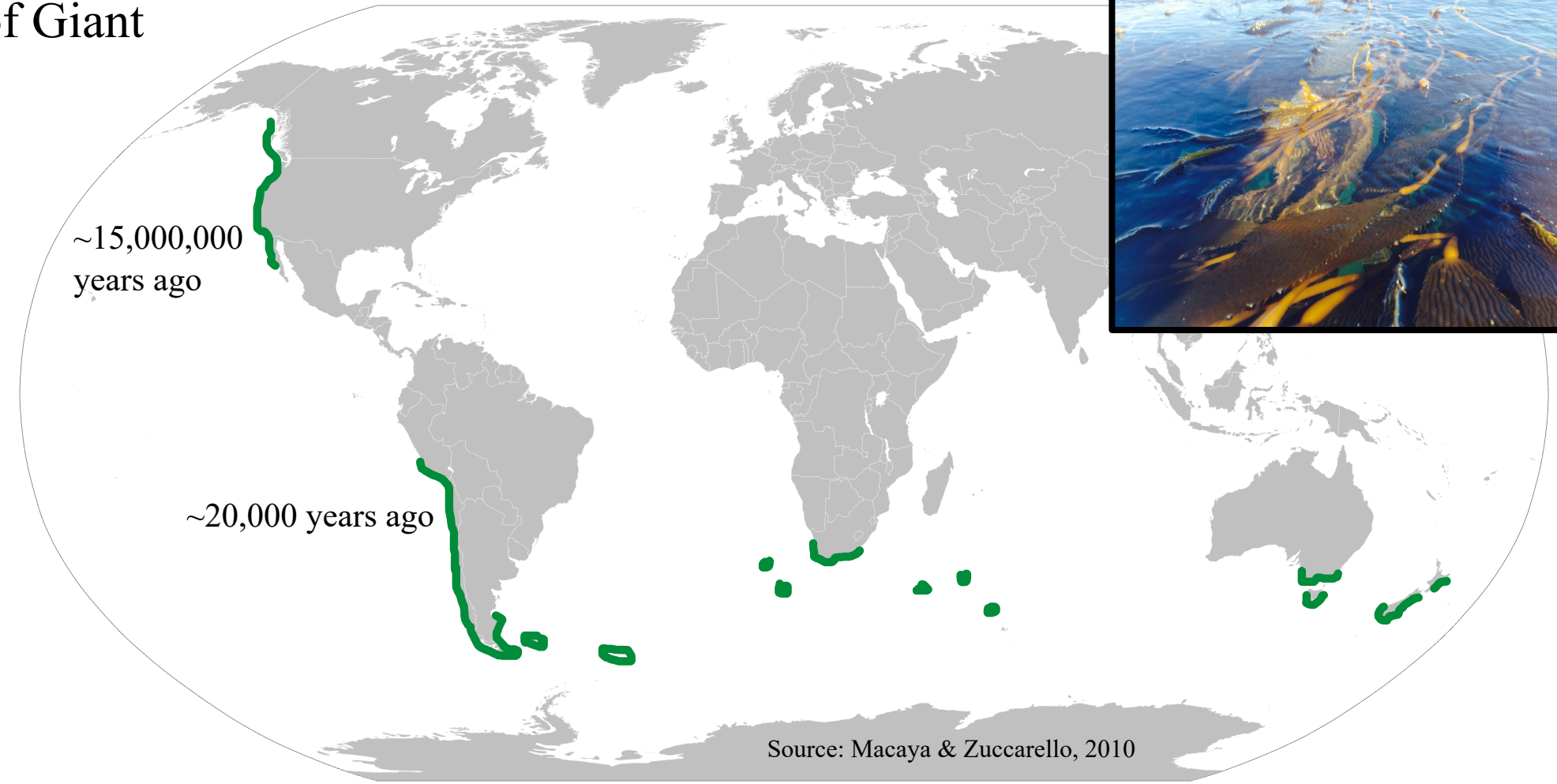


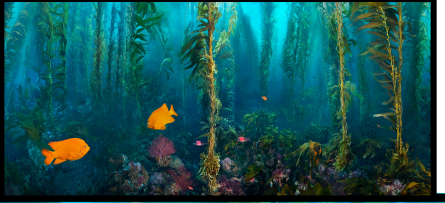
Source: Krumhansl et al., (2016)



Background - Distribution

Distribution of Giant Kelp





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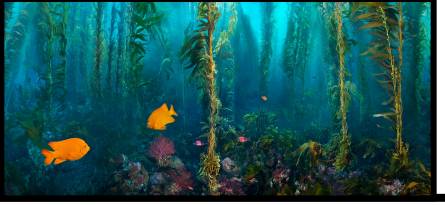
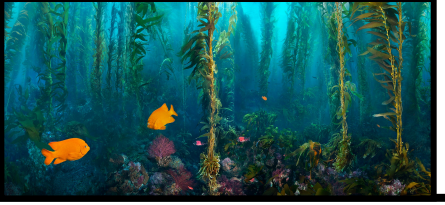


Methods - Overview

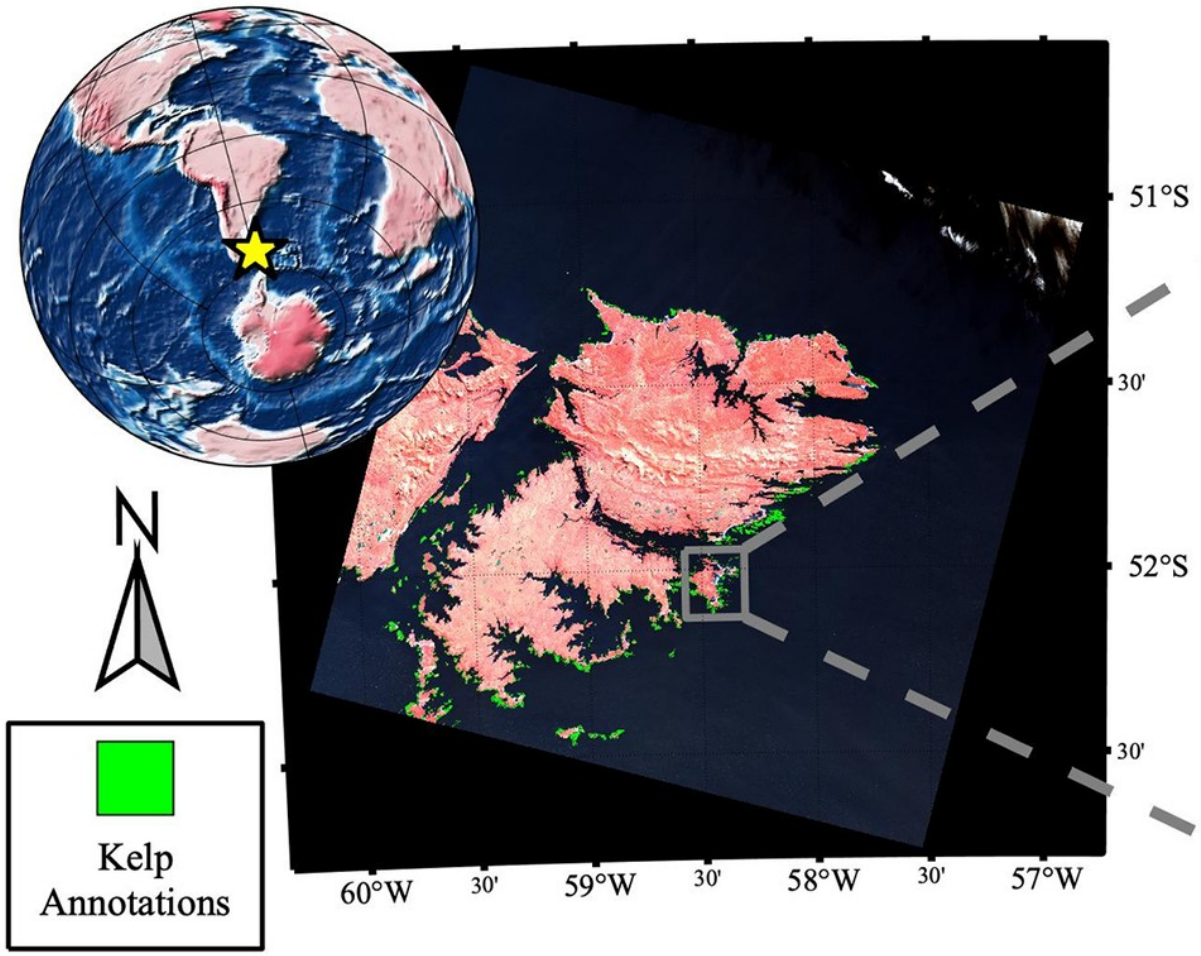
Giant kelp blades lie very near the surface of the water and reflect near infrared light.

Detectable using high-spatial resolution satellite imagery with a near-infrared channel.

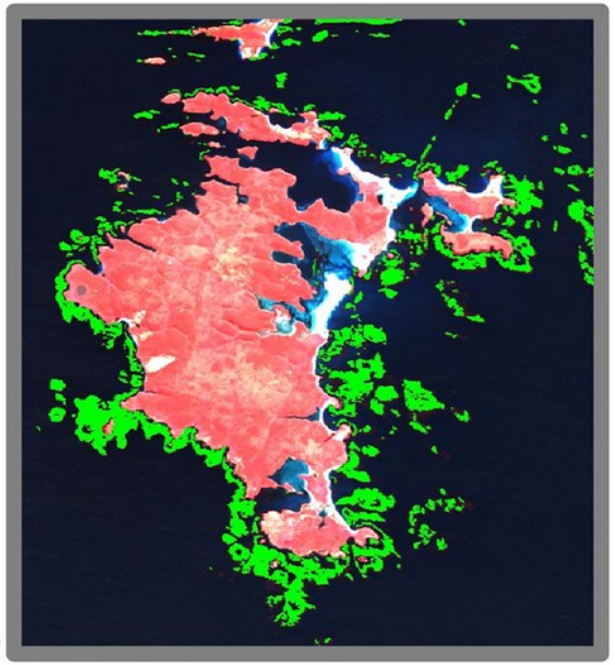


Methods - Manual

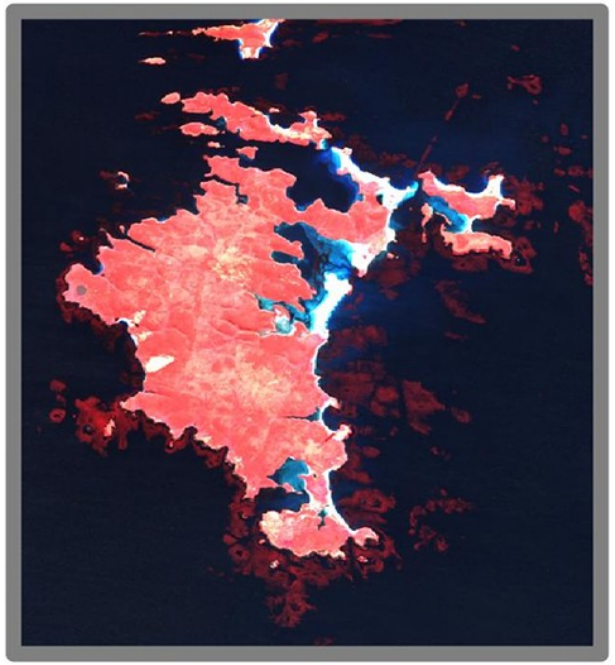
Landsat (OLI) image of East Falkland



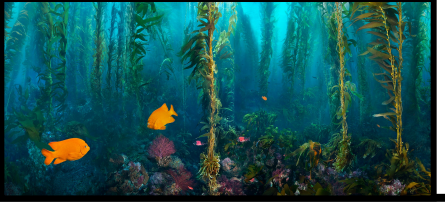
Expert (manual)



Pseudo Color



Houskeeper, Rosenthal, Cavanaugh, Pawlak, Trouille, Byrnes, Bell, & Cavanaugh (2022) *PLoS ONE*.



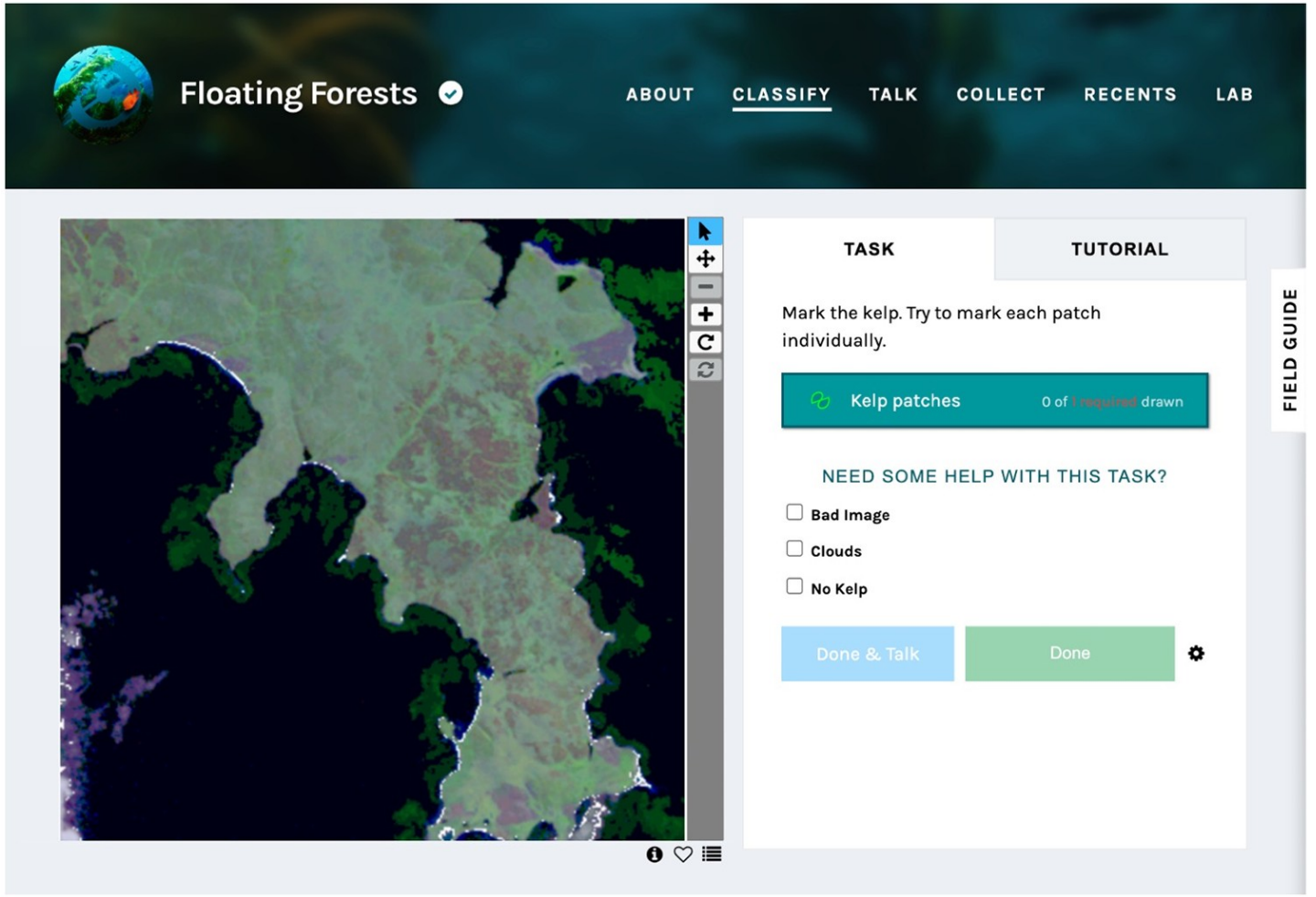
Methods – Floating Forests

The Floating Forests project

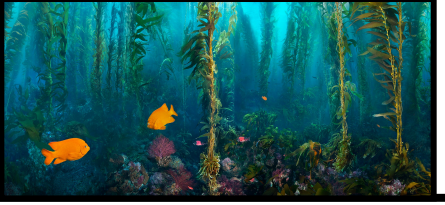
Citizen scientists use the Zooniverse portal to view image tiles and identify kelp canopy patches

We apply a consensus threshold per 15 unique viewers to determine kelp presence.

Citizen scientists view RGB imagery, with the green band enhanced as a function of the NIR band.

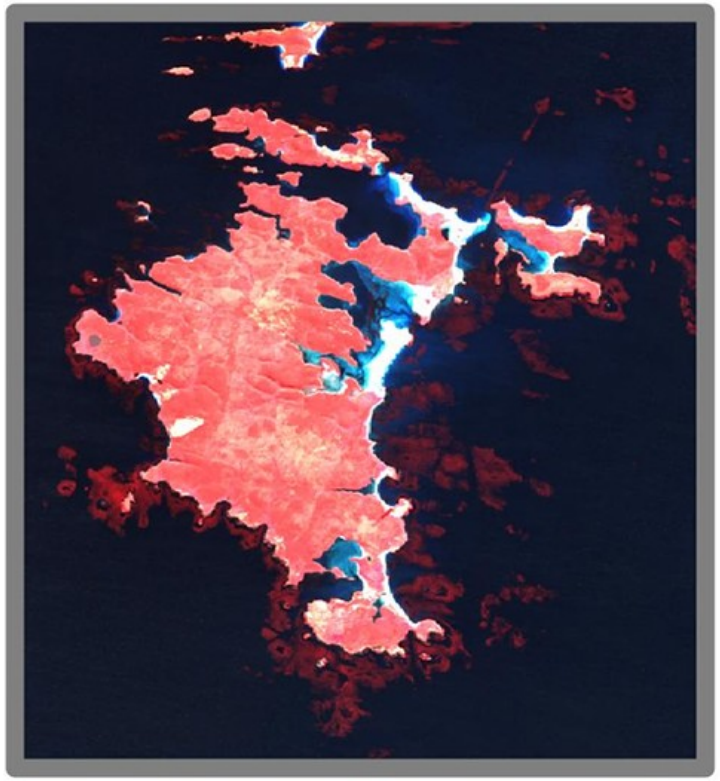


Houskeeper, Rosenthal, Cavanaugh, Pawlak, Trouille, Byrnes, Bell, & Cavanaugh (2022) *PLoS ONE*.

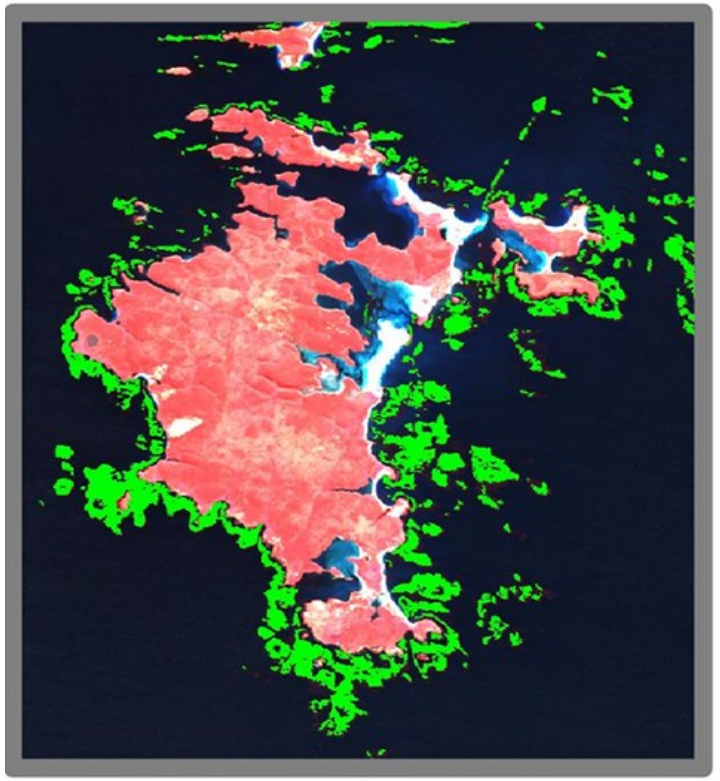


Methods – Floating Forests

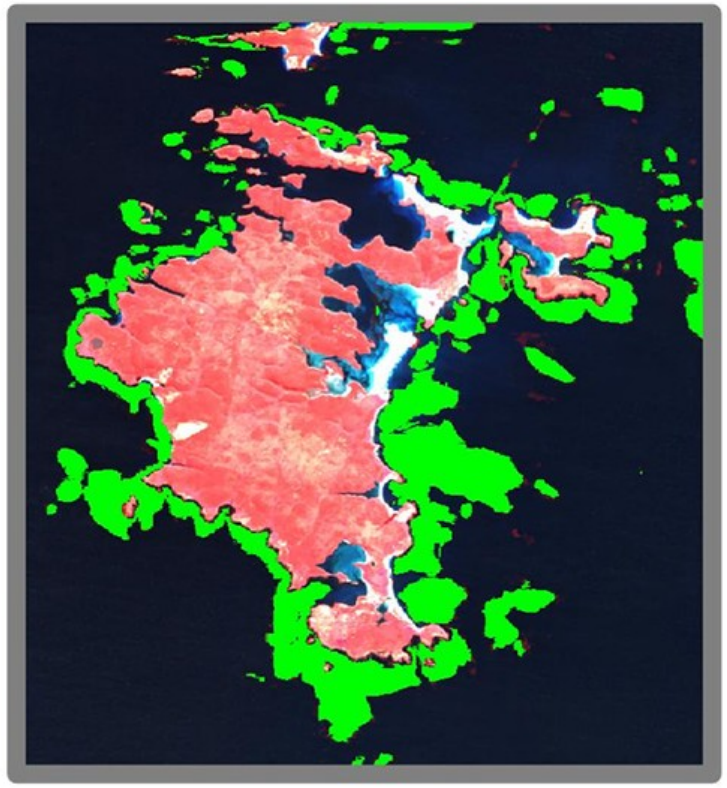
Pseudo Color



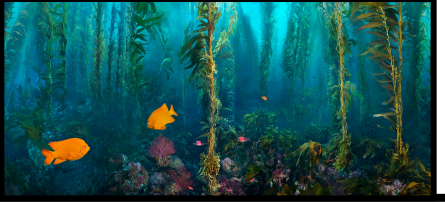
Expert (manual)



Floating Forests / Citizen Science



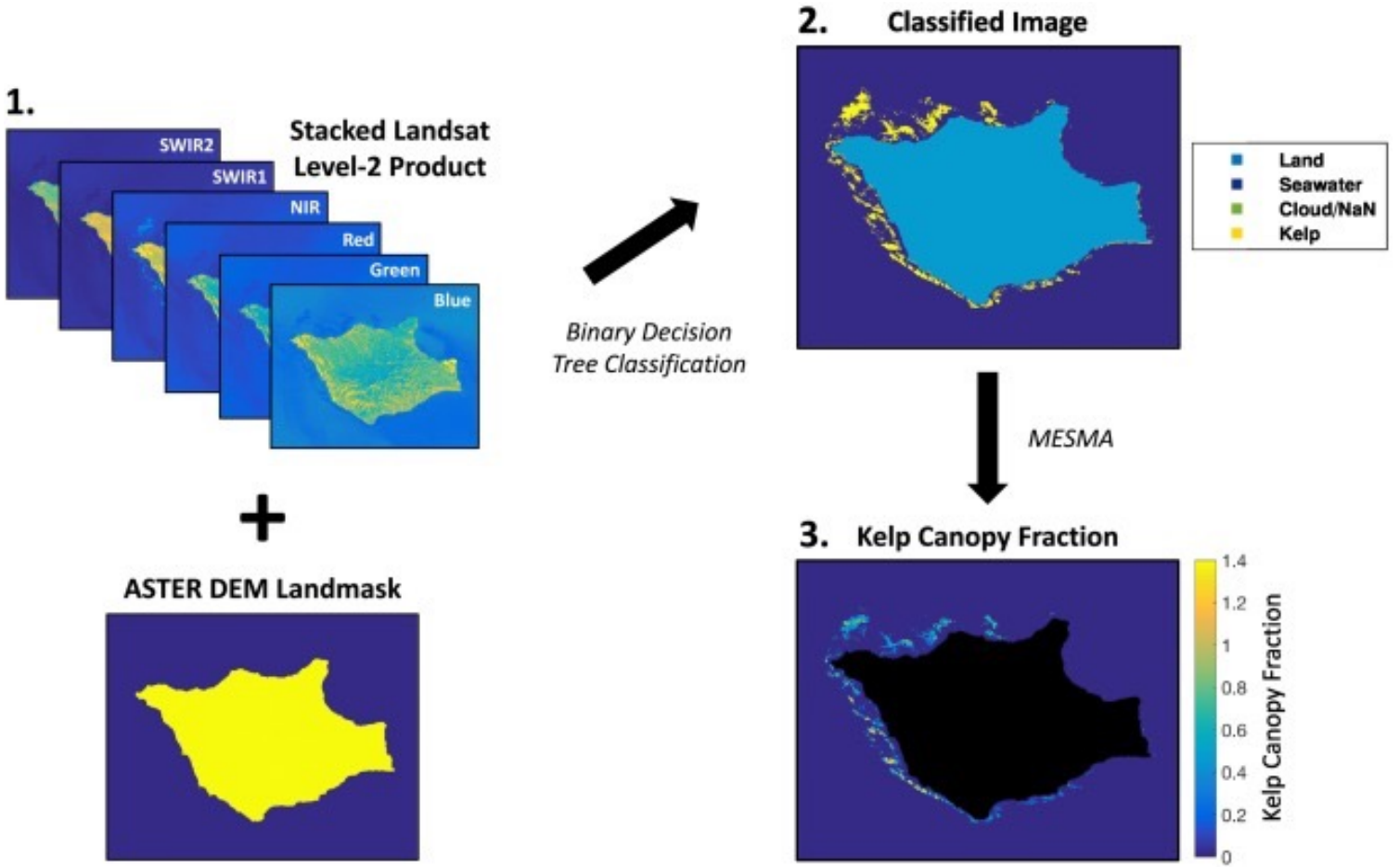
Houskeeper, Rosenthal, Cavanaugh, Pawlak, Trouille, Byrnes, Bell, & Cavanaugh (2022) *PLoS ONE*.



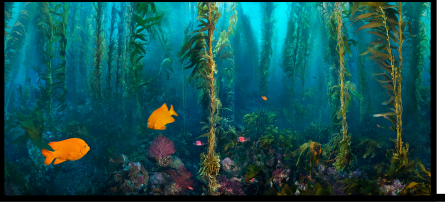
Methods – Spectral Unmixing

Decision tree paired with a spectral unmixing approach evaluates pixel-by-pixel fractional canopy coverage.

Recently automated using Google Earth Engine (GEE).

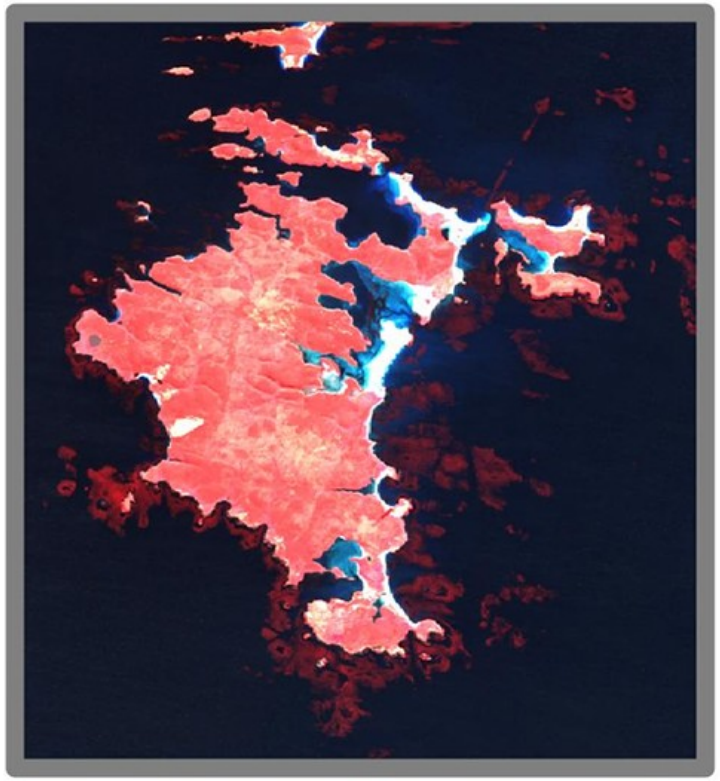


Bell, Allen, Cavanaugh, & Siegel (2020) *Remote Sensing of Environment*.

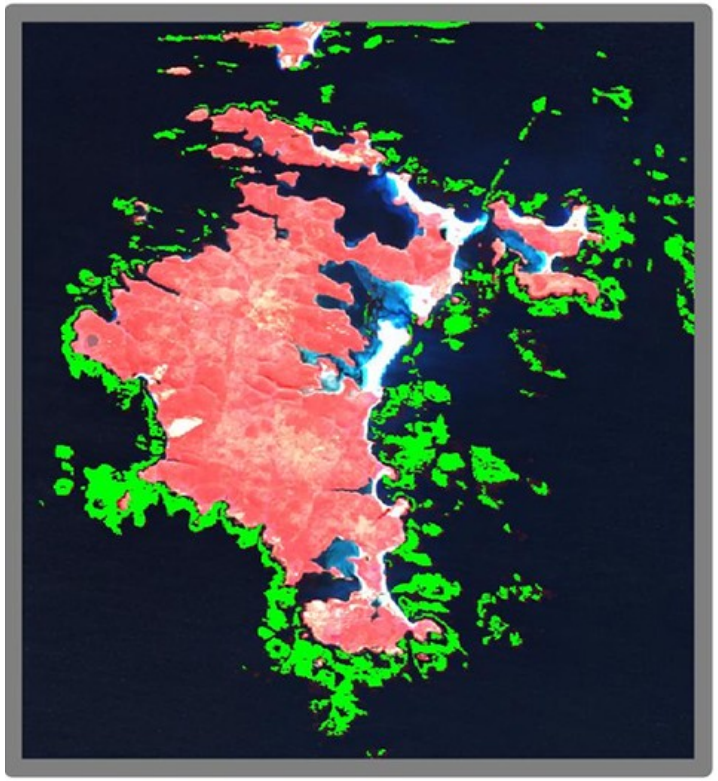


Methods Comparison

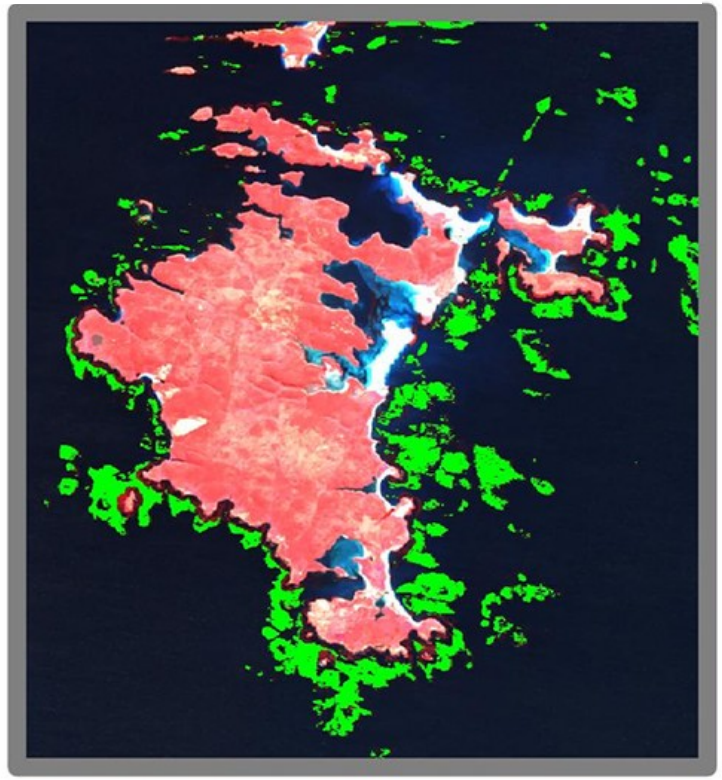
Pseudo Color



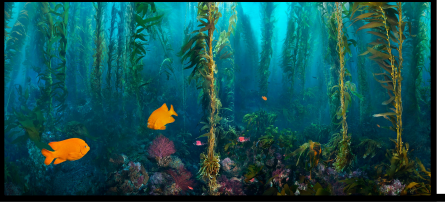
Expert (manual)



Decision Tree + Spectral Unmixing



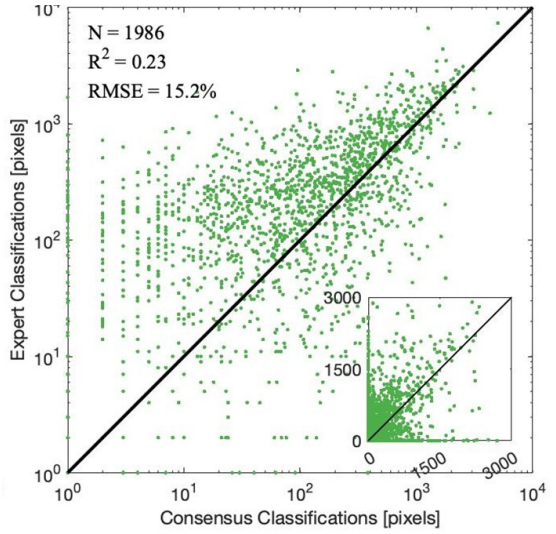
Houskeeper, Rosenthal, Cavanaugh, Pawlak, Trouille, Byrnes, Bell, & Cavanaugh (2022) *PLoS ONE*.



Methods Comparison

Citizen Science

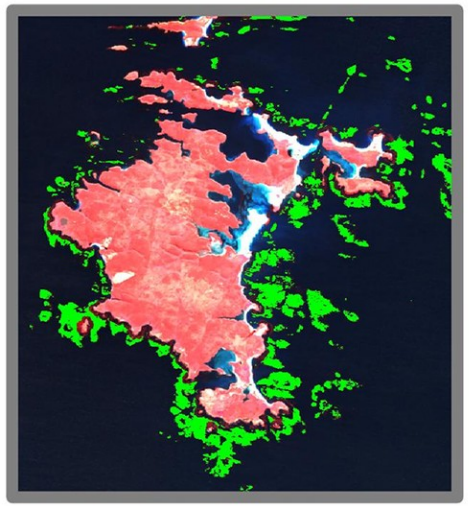
(primarily spatial information)

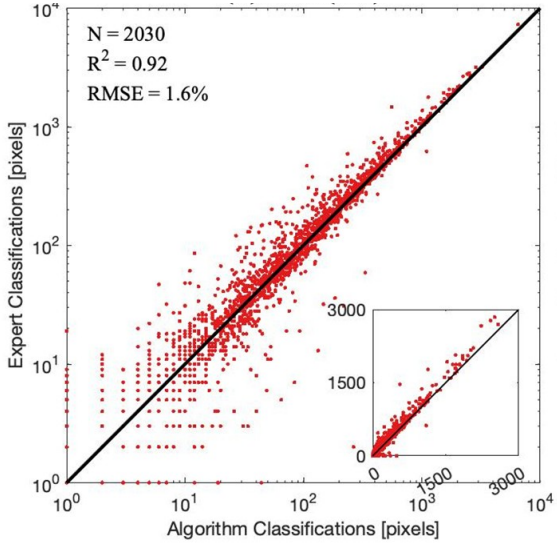


Spectral unmixing approach produces the highest accuracy, but still fails for bright NIR pixels.

Spectral Unmixing

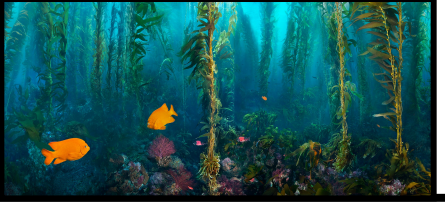
(only spectral information)





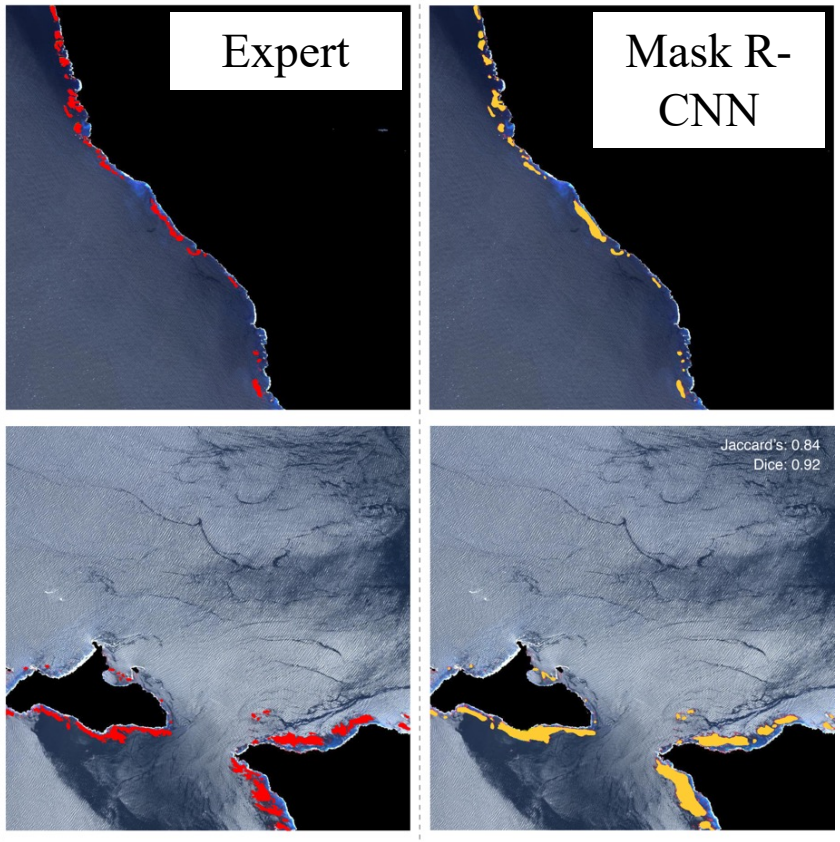
We'd like to capture both spectral and spatial information.

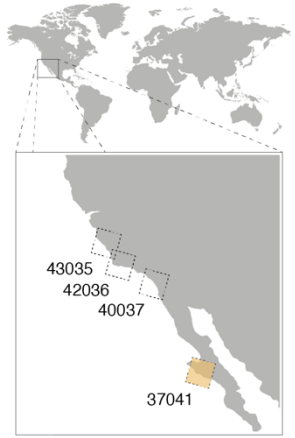
Houskeeper, Rosenthal, Cavanaugh, Pawlak, Trouille, Byrnes, Bell, & Cavanaugh (2022) *PLoS ONE*.

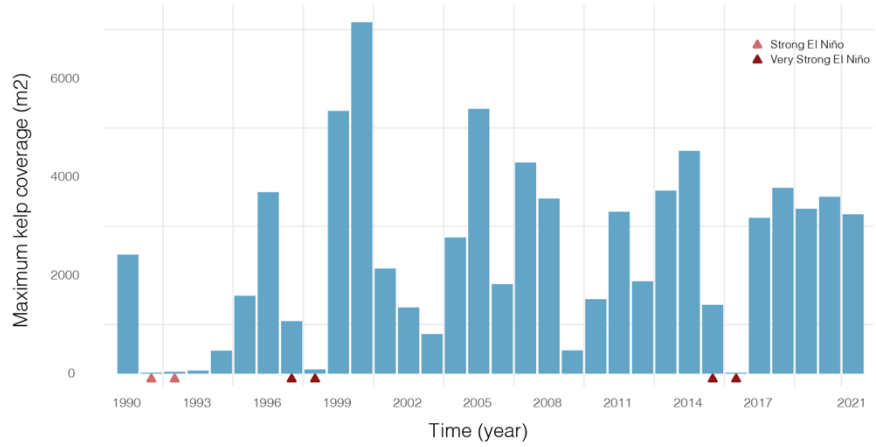


Methods Comparison

Mask R-CNN is a convolutional neural network used for image segmentation (developed by industry AI researchers)



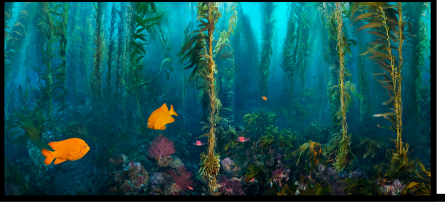




We trained a Mask R-CNN model using a U.S. west coast kelp forest image library (Landsat).

Model applied to develop time series for Baja California regions near southern range limit.

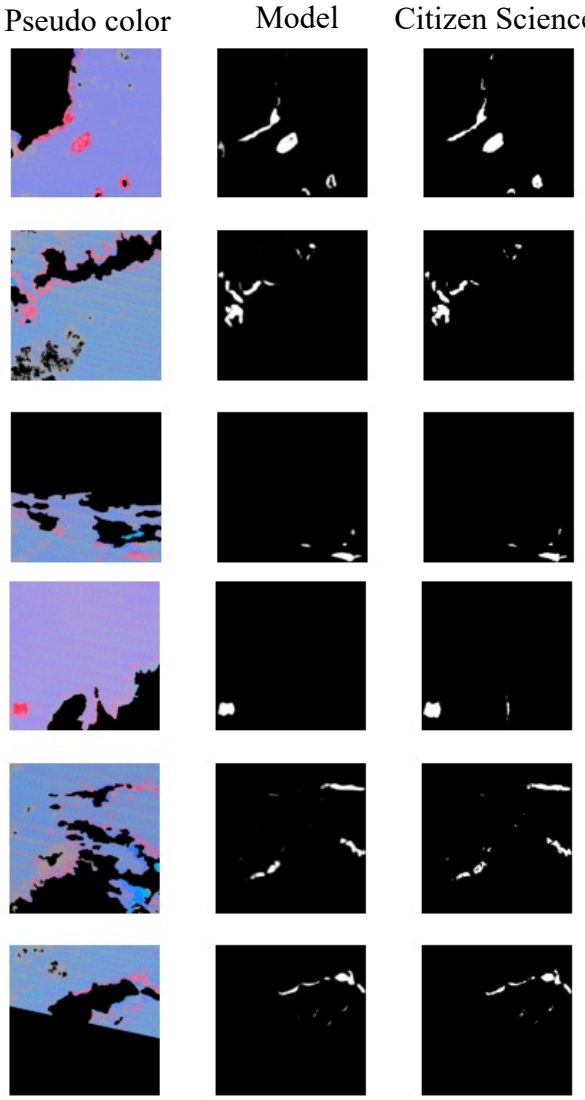
Marquez, Fragkopoulou, Cavanaugh, Serrão, Houskeeper, & Assis (In Review) *Journal of Remote Sensing*.



Methods Comparison

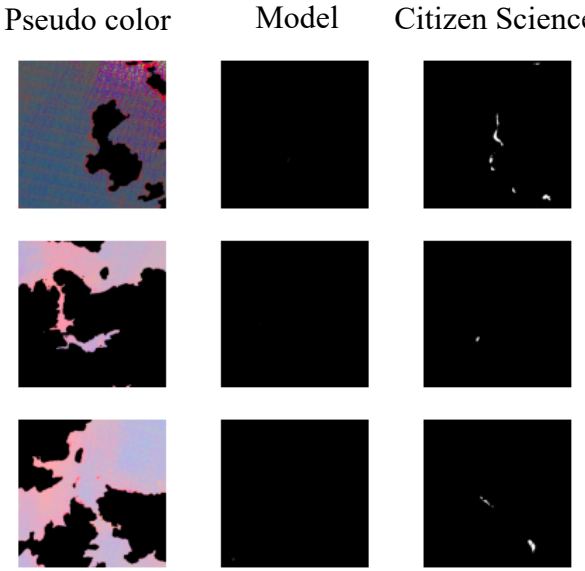
Preliminary results from another image segmentation approach using EmbedSeg model (Lalit et al., 2022).

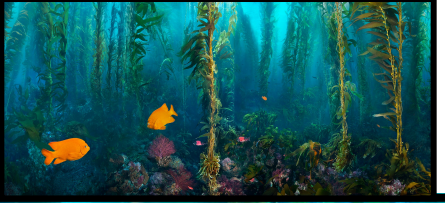
Collaboration led by Ramanakumar Sankar, a postdoctoral researcher at University of Minnesota.



Training performed using citizen science classifications from Falkland Islands dataset.

Next steps: Model failing when channel normalization poor





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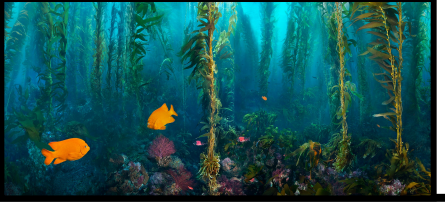
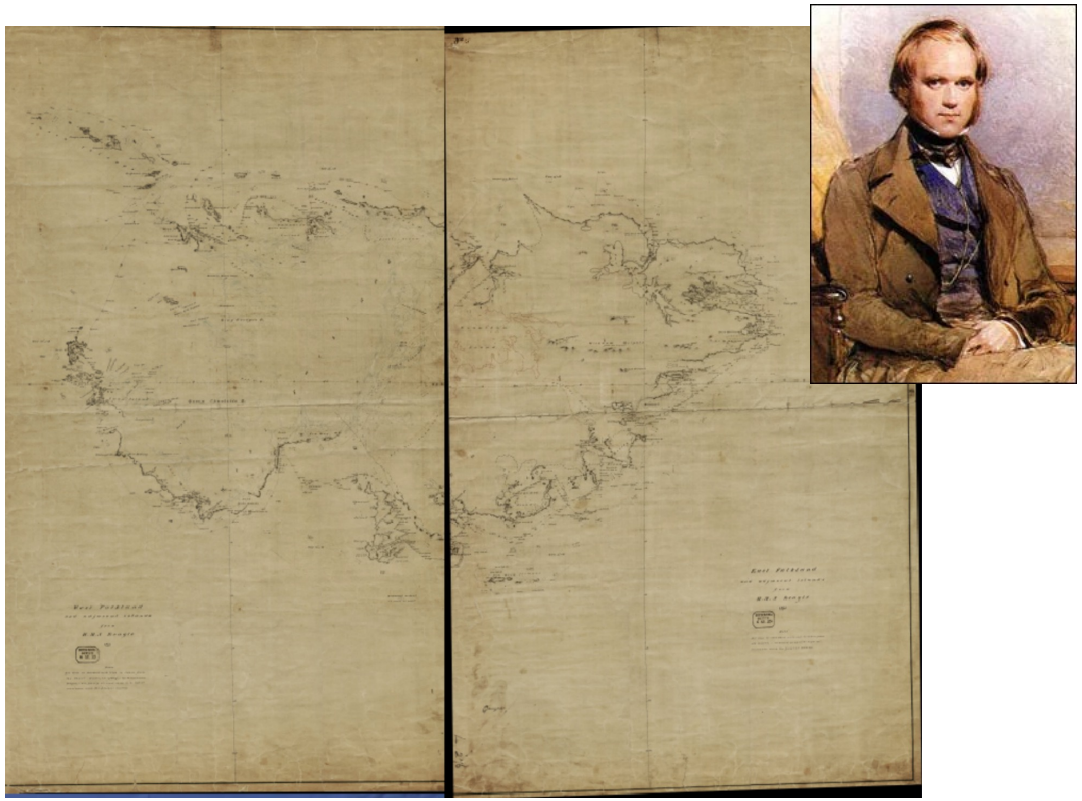
Results shown are based on the spectral unmixing method, unless otherwise stated

Photo: J. Heller

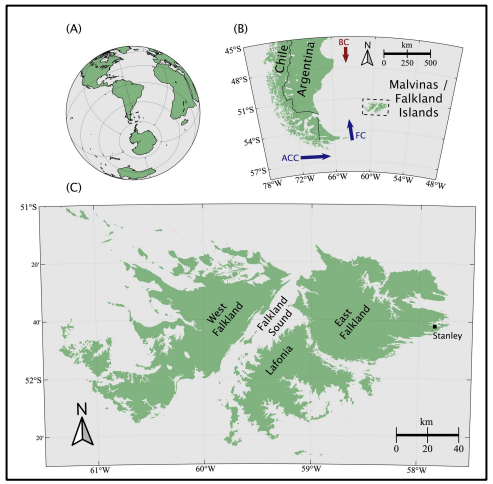


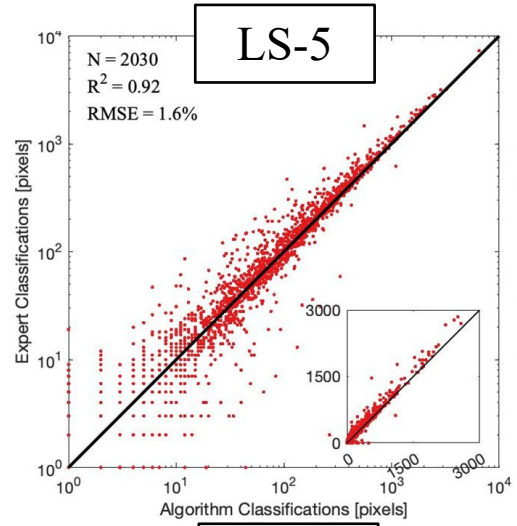
Regional Results

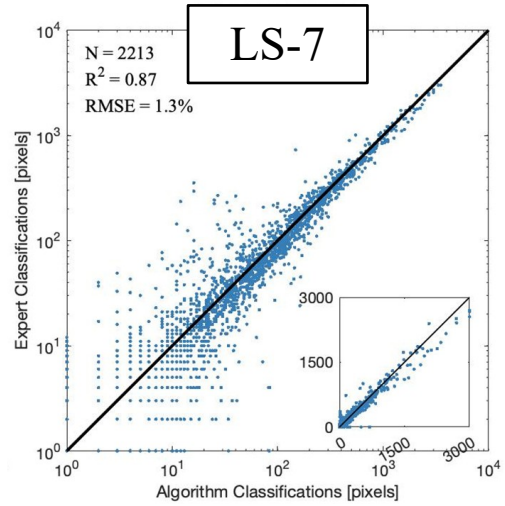
Giant kelp forests in the Falkland Islands were surveyed over a century ago by HMS Beagle

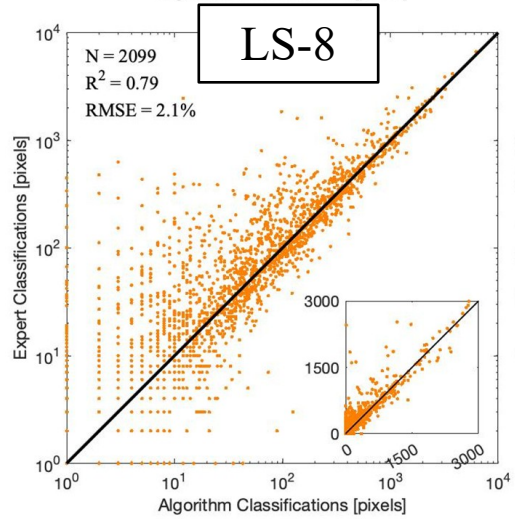


Mora-Soto et al. (2021) *Journal of Biogeography*.



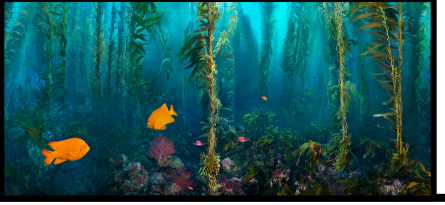






Inter-sensor agreement for Falkland Islands Landsat classifications

Houskeeper et al. (2022) *PLoS ONE*.

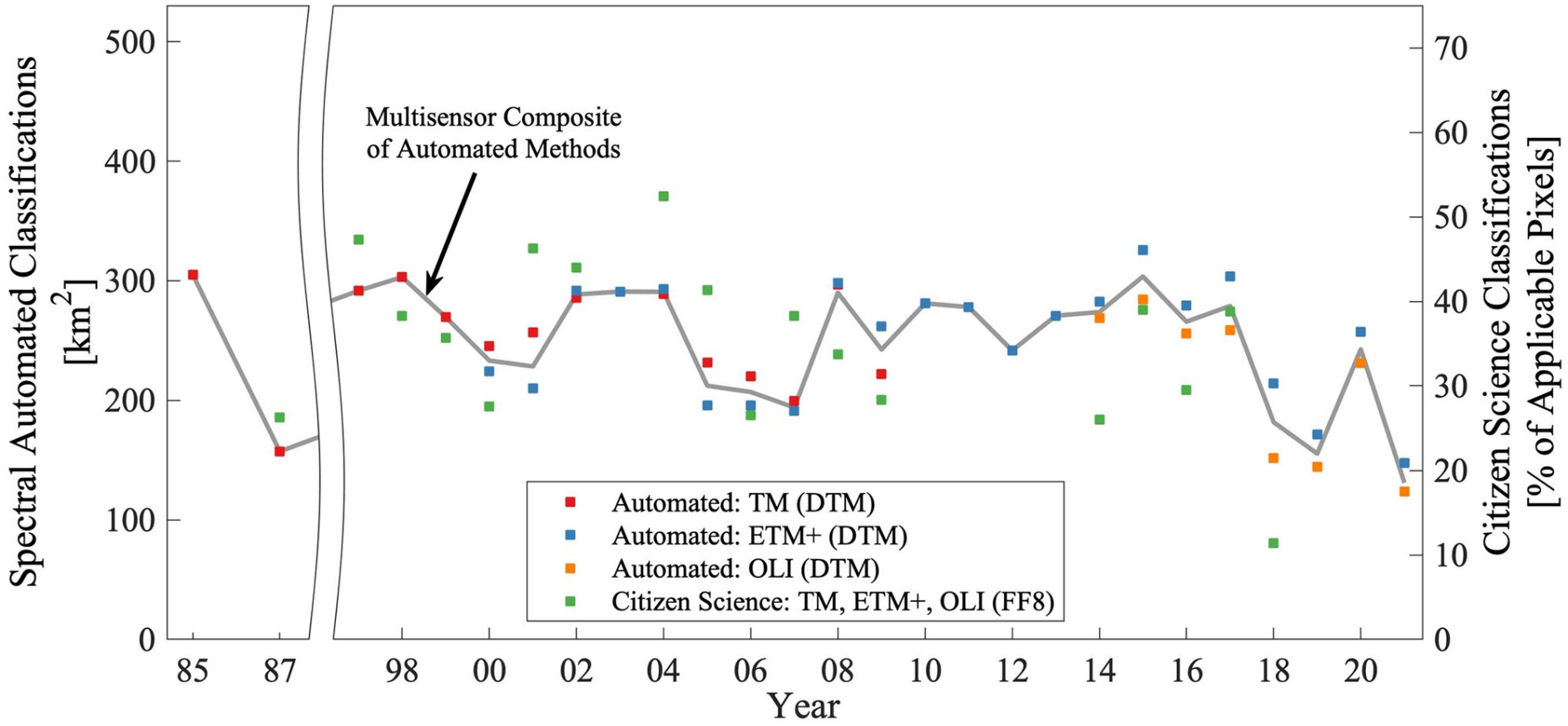


Regional Results

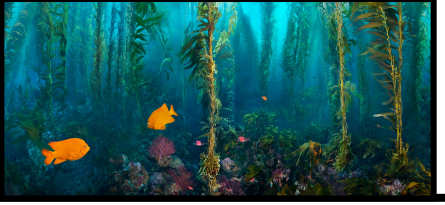
Recent declines possible, although a decline with similar scale was observed in 1985-87.

Citizen science data products (green) capture similar temporal variability.

Canopy area time series for Falkland Islands

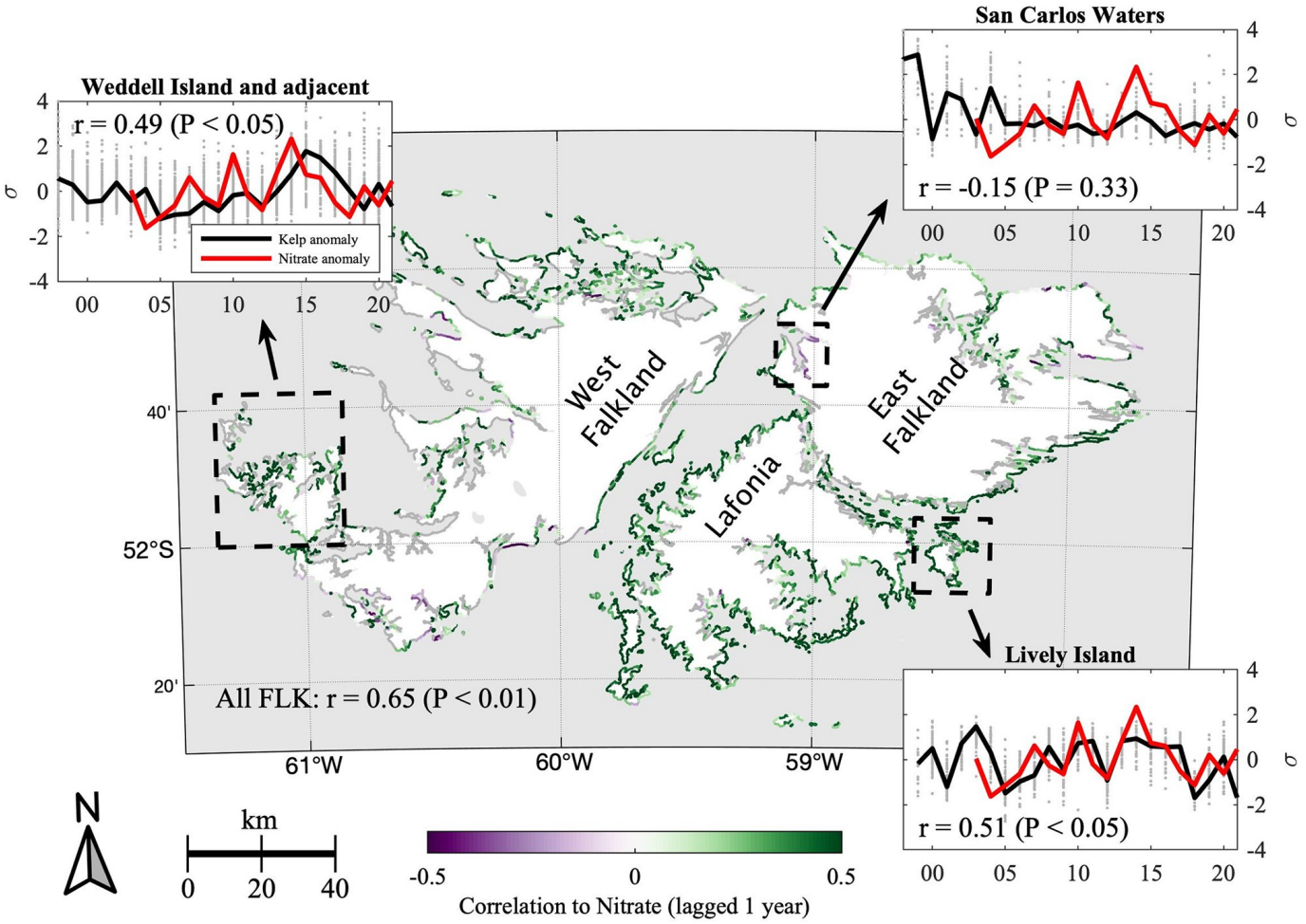


Houskeeper, Rosenthal, Cavanaugh, Pawlak, Trouille, Byrnes, Bell, & Cavanaugh (2022) *PLoS ONE*.



Regional Results

Canopy area correlation with temperature or nitrate

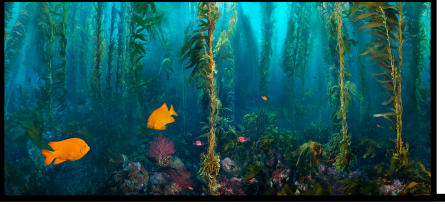


Tests performed at 1km granularity.

Most regions indicated significant positive (negative) correlation to nitrate (or temperature).

Regions with weak correlation generally had few kelp patches, e.g., San Carlos Waters.

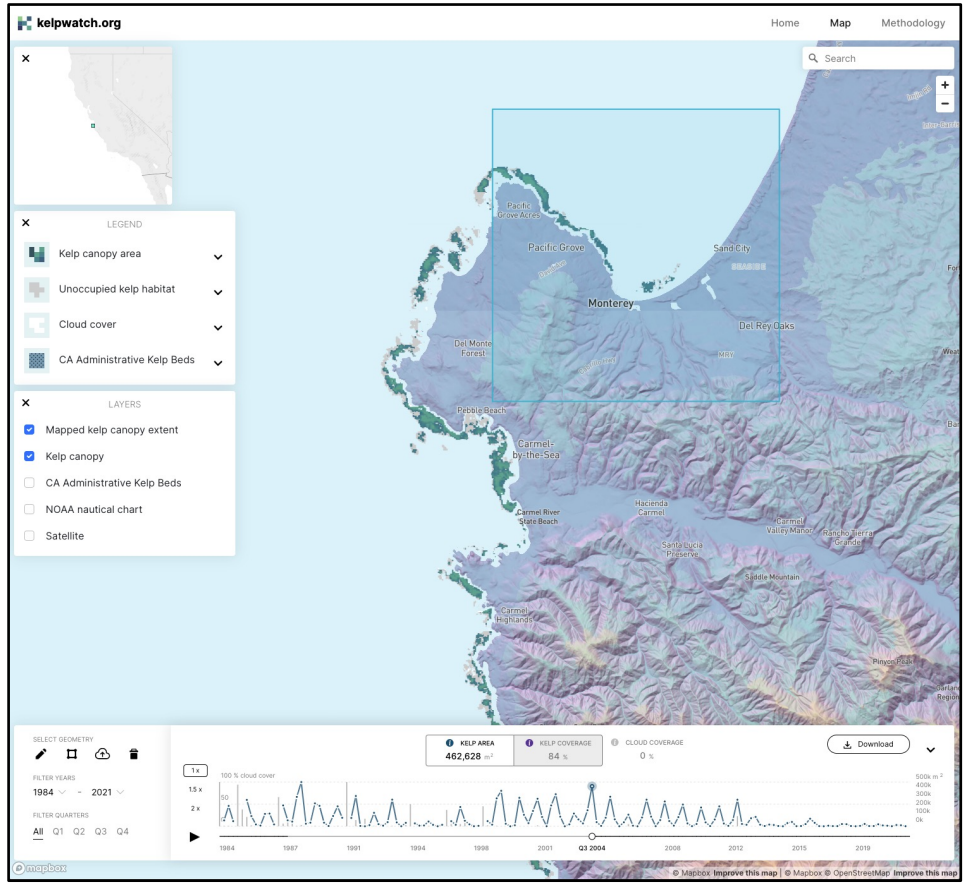
Houskeeper, Rosenthal, Cavanaugh, Pawlak, Trouille, Byrnes, Bell, & Cavanaugh (2022) *PLoS ONE*.



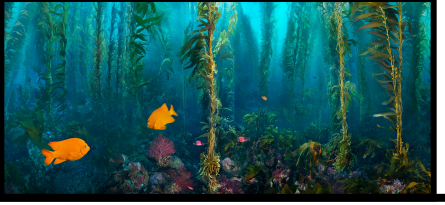
Regional Results

Recently we've partnered with the Nature Conservancy to launch an interactive data visualization tool: https://kelpwatch.org/

We've performed a re-analysis of U.S. west coast canopy using the data products as accessed from KelpWatch.

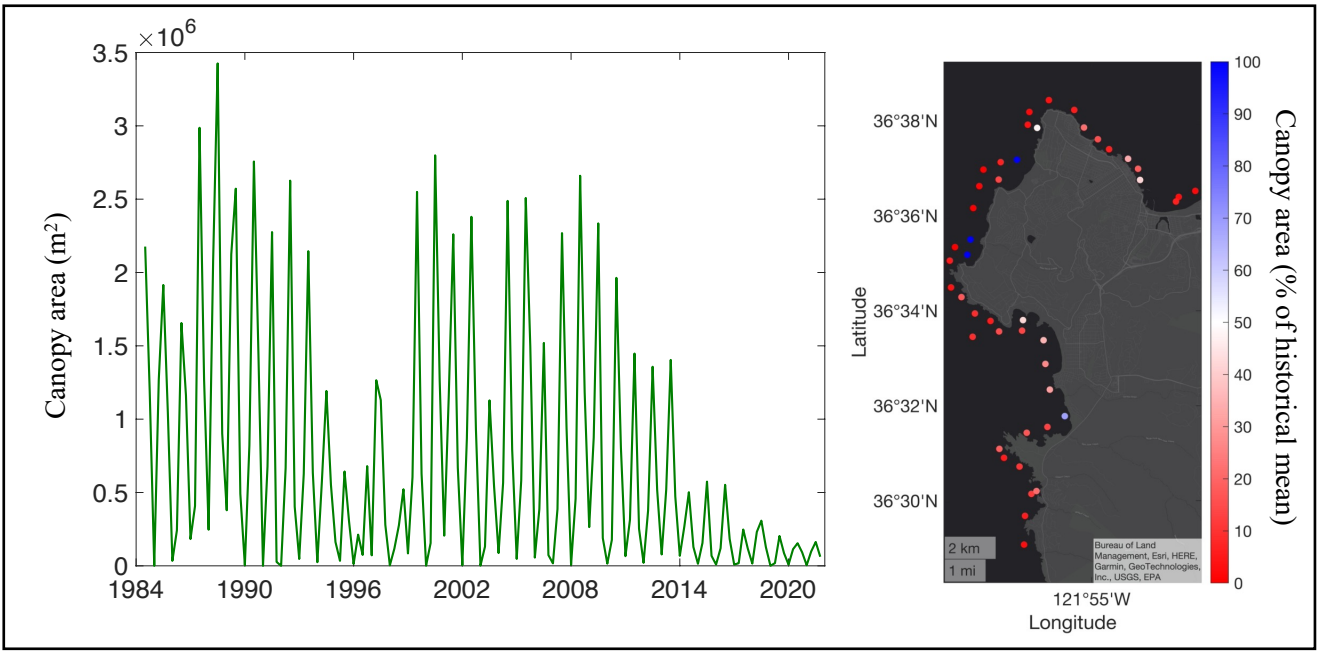


Bell, Cavanaugh, Saccomanno, Cavanaugh, Houskeeper, Eddy, Schuetzenmeister, Rindlaub, Gleason (In Review) *PLoS ONE*.

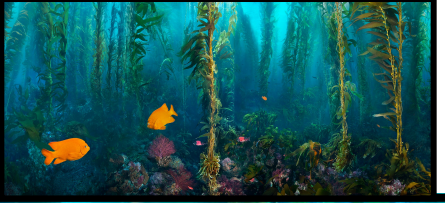


Regional Results

Canopy area along the Monterey Peninsula shows a slow decline with patchy recovery compared to the rest of the central California region.



Bell, Cavanaugh, Saccomanno, Cavanaugh, Houskeeper, Eddy, Schuetzenmeister, Rindlaub, Gleason (In Review) *PLoS ONE*.

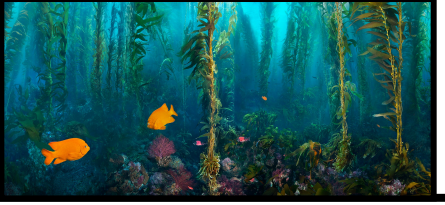


Remote monitoring of kelp forest ecosystems.

Outline

- Background
- Methods
  - Citizen Science
  - Spectral Unmixing
  - Artificial Intelligence
- Regional Results
  - Falkland Islands (Islas Malvinas)
  - U.S. West Coast and Baja California
- Next steps

Photo: J. Heller



Next Steps / Ongoing Projects

Floating Forests

Collaboration with Jarrett Byrnes, Isaac Rosenthal, Laura Trouille, Tom Bell, Kyle Cavanaugh, and many others.

★ Kelp on the Edge

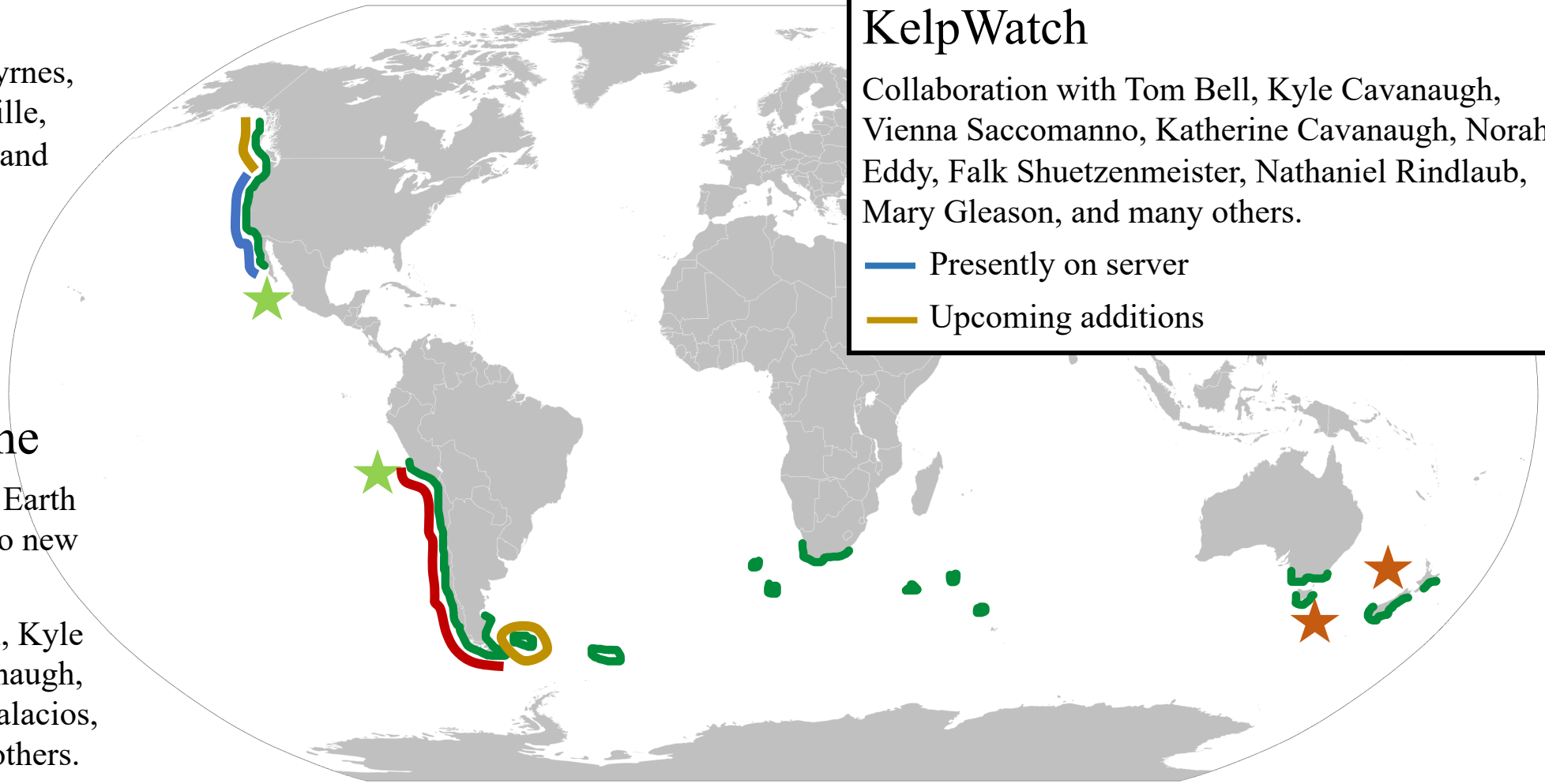
★ Pipeline targeting: Tasmania and New Zealand

Google Earth Engine

Continue to develop Google Earth Engine pipeline to scale up to new regions

Collaboration with Tom Bell, Kyle Cavanaugh, Katherine Cavanaugh, Alejandra Mora, Mauricio Palacios, Erasmo Macaya, and many others.

— Upcoming analysis

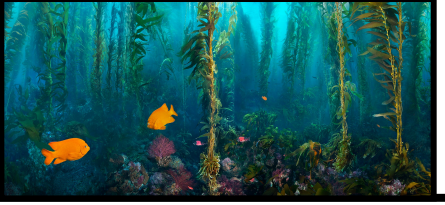


KelpWatch

Collaboration with Tom Bell, Kyle Cavanaugh, Vienna Saccomanno, Katherine Cavanaugh, Norah Eddy, Falk Shuetzenmeister, Nathaniel Rindlaub, Mary Gleason, and many others.

— Presently on server

— Upcoming additions



Collaborators and Funding

UC Los Angeles
Kyle Cavanaugh
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Alejandra Mora-Soto

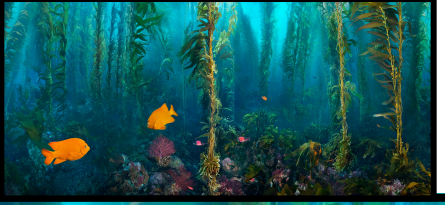
U Concepción
Erasmo Macaya

The Nature Conservancy
Vienna Saccomanno
Falk Schuetzenmeister
Nathaniel Rindlaub
Norah Eddy
Mary Gleason

Wildlife Conservation Society
Mauricio Palacios

Zooniverse
Laura Trouille

And many others….



Thank you

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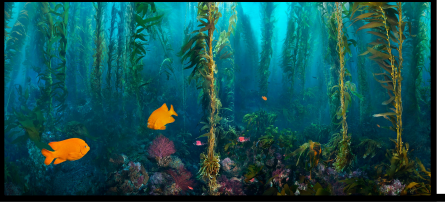
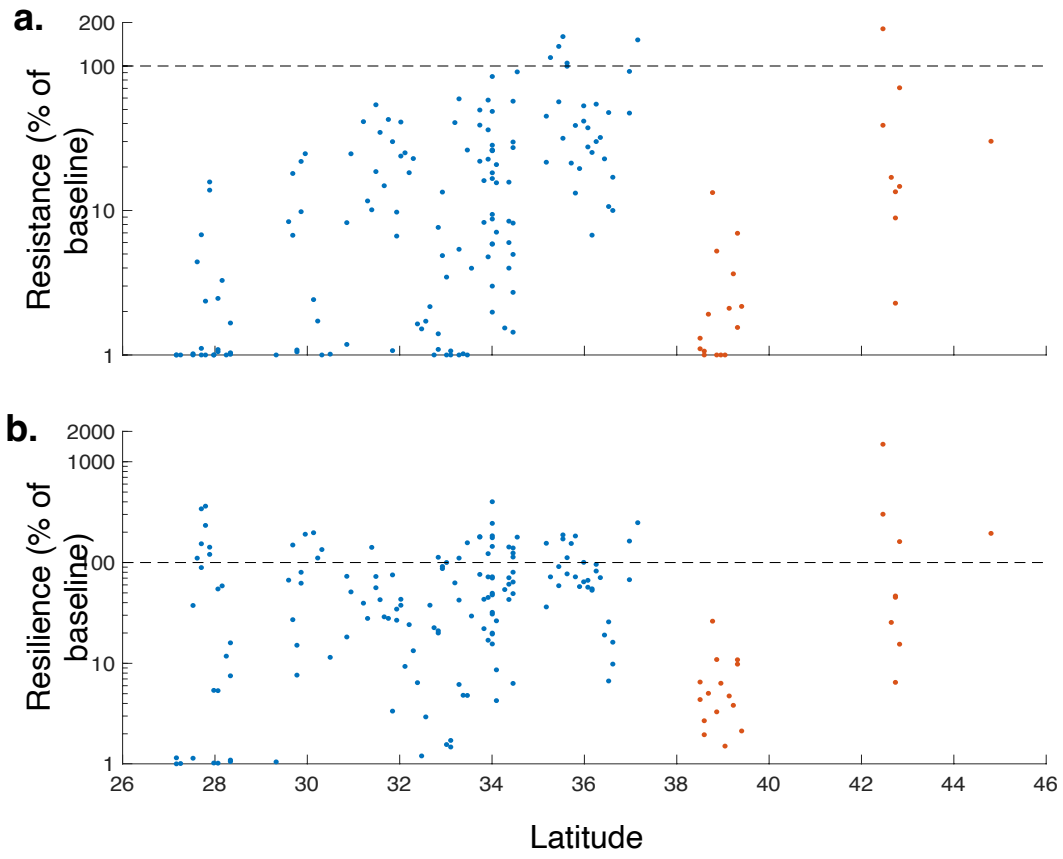
Photo: J. Heller



Regional Results

Results from U.S. West Coast re-analysis of spectral unmixing approach.



Resistance: stability following a disturbance event.

Resilience: recovery following a disturbance event

Data suggests a possible latitudinal gradient in resistance.

Bell, Cavanaugh, Saccomanno, Cavanaugh, Houskeeper, Eddy, Schuetzenmeister, Rindlaub, Gleason (In Review) *PLoS ONE*.