**All references and supplemental figures are hyperlinked to the online material*

Interests: I use a combination of field and laboratory studies, statistical and mechanistic models, and remote sensing to understand how coastal oceanographic processes structure the abundance and physiology of marine foundation species (e.g. algae[1,2,3,4], corals[5], seagrasses[6]). Foundation species structure entire ecological communities, which are often economically important, by creating physical habitat and enhancing productivity. Thus, fundamental research which quantifies how a changing coastal environment interacts with foundation species dynamics may lead to a greater understanding of their associated community.

Since foundation species tend to be conspicuous, they lend themselves to remote observation and represent one of the best opportunities for quantifying ecosystem dynamics across scales. The impacts of environmental drivers vary spatially due to differences in driver magnitude, extirpation of keystone species (e.g. sea otters), or ecotypic variation. Additionally, complex factors intrinsic to the population of interest, such as physiological response, age at senescence, and demographics, may lead to abundance patterns which defy our expectations if we only consider the effects of the external environment. **My research is motivated by understanding how the extrinsic coastal environment and intrinsic biotic factors drive the population and physiological dynamics of foundation species over local to global scales.** I approach my work by integrating laboratory physiological measurements and field studies with emerging remote sensing technologies (e.g. hyperspectral imaging, unmanned vehicles, cloud-based processing tools) to more effectively understand ecosystem processes over large spatial and temporal scales. This combination has the potential to provide a synoptic view of large-scale ecosystem processes that was unimaginable a decade ago. **My background and training make me well suited to answer critical questions in coastal oceanography and bio-physical interactions, many of which require an understanding of processes over diverse spatial and temporal scales.**

Activities: ***1.*** Giant kelp is a globally distributed foundation species whose abundance dynamics are sensitive to multiple environmental forces. Giant kelp is an excellent model species to examine the effects of a changing environment on abundance, physiology, and demographic dynamics due to its rapid growth and recovery cycles and its conspicuous floating surface canopy, which is amenable to remote sensing. As part of my PhD dissertation I improved and automated image processing methods to scale a regional canopy biomass dataset derived from a single defunct satellite sensor to one that spans the entire state of California and Baja California, Mexico and continues to the present day by calibrating data from active satellite sensors[4]. I used this spatial time series to examine the dominant environmental drivers of canopy dynamics, the relative importance of wave disturbance, nutrient supply, herbivory, and climate oscillations across time and space, and identify critical driver thresholds[1]. This work was highlighted in the recent *National Academies* Decadal Strategy for Earth Observation (**Fig. S1**). This study reconciled conflicts among many local scale studies concerning the relative importance of different environmental drivers of kelp dynamics[1]. My work also highlighted the role of decadal marine climate oscillations in driving large-scale kelp abundance dynamics, showing the importance of understanding long-term patterns to accurately quantify the effects of anthropogenic climate change[1,4]. While any data I produce will always be public, it can often be difficult for some users to access due to the nature of 'big data'. Currently, I am working with The Nature Conservancy (TNC) to develop a visualization/data access tool called *KelpWatch* (live early 2020; **Fig. S2**) so anyone can easily download the kelp data time series specific to their area(s) of interest, regardless of their computing background. I was also funded by TNC to move my image processing code to Google Earth Engine to expand the spatial extent of the time series to cover the entire Eastern Pacific (B2B: Bering to Baja project). I am currently leveraging data from this cloud-based processing platform to examine state change (bare rocky reef ⬌ kelp forest) in response to sea otter recolonization across southeast Alaska.

2. I used a combination of field monitoring, laboratory analysis, and remote sensing methods to understand how the physiological condition of the giant kelp canopy changes in response to environmental drivers and spatially structures kelp populations. I found that the ratio of chlorophyll *a* to carbon content (Chl:C; a physiological proxy) was non-linearly related to seawater nitrate concentration and available light and was essential to increases in kelp biomass accumulation and rates of net primary production[3]. I paired the Chl:C data with laboratory blade reflectance measurements and developed a spectral algorithm to estimate Chl:C using aerial hyperspectral imagery (JPL's AVIRIS aerial imagery, 2013 – 2015)[2]. The spatial patterns of canopy Chl:C determined from the imagery were associated with different drivers depending on the scale of observation. At a regional scale (1 – 100 km) Chl:C patterns were negatively related to seawater temperature (**Fig. S3**; temperature is inversely and non-linearly related to nitrate concentration; **Fig. S4**). However, at local scales (10 m – 1 km) Chl:C patterns were negatively related to canopy age (**Fig. 1**). The decline of Chl:C with age mirrors the empirical kelp frond loss rate due to senescence (**Fig. S5**), where frond lifespan is ~100 days and is unaffected by nutrient conditions. Areas with reduced physiological condition emerged early in the season and contained a higher proportion of senescing fronds, losing canopy more quickly than areas which had emerged more recently. These results are important because they help disentangle the roles of regional nutrient supply (rapid growth from upwelled nitrate) and local biotic factors (variable declines due to age demographics) on kelp population dynamics, and show the power of large-scale, spatially continuous measurements to identify emergent patterns and their underlying processes.

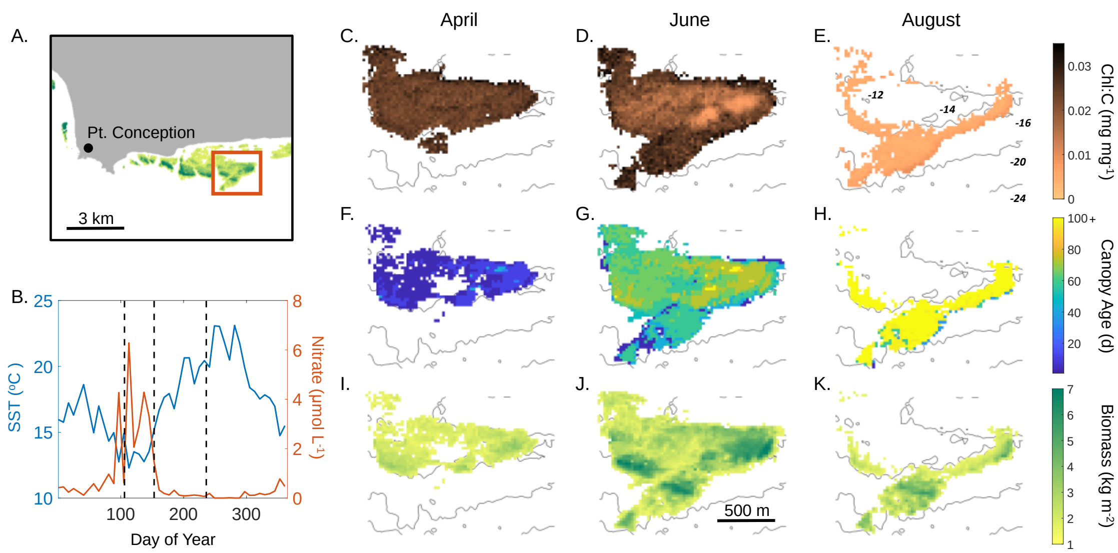

Fig. 1. Local-scale patterns of physiological condition, canopy age, and canopy biomass over a growing season with areas of low physiological condition in June presaging canopy loss in August. These results show that physiological condition declines with canopy age and is related to the senescence of giant kelp fronds. (**A**) Western Santa Barbara Channel with kelp forest in red box. (**B**) Time series of surface temperature (blue) and nitrate concentration (red) near the kelp forest and dashed black lines show the dates of hyperspectral imagery in 2015. (**C - E**) Chl:C (AVIRIS, 18m pixels), (**F - H**) canopy age and (**I - K**) canopy biomass density (Landsat, 30m pixels) for the kelp forest across the three dates. Black lines represent bathymetry (meters).

3. As part of my postdoctoral work at UCLA, I used an unprecedented set of aerial hyperspectral imagery, underwater field spectroscopy, and water column inversion techniques to investigate the impact of water column properties (i.e. depth, chlorophyll, sediment, CDOM, wind) on the estimation of fractional coral reef benthic cover in Hawaii (*methods schematic* **Fig. S6**)[5]. Using this framework, I determined the mean absolute error associated with the estimation of coral reef benthic classes in modeled water columns with varying water properties (**Fig. S7**). This work was completed to establish 'best practices' for coral reef monitoring in advance of nascent hyperspectral satellite missions like NASA's Surface Biology & Geology (*planned launch mid-2020's*). I then applied these model results to the aerial hyperspectral imagery of Molokai, Hawaii to produce maps of fractional benthic cover and uncertainty associated with the benthic cover estimates (**Fig. 2**). This work underpins one of my future research goals (*see Major Planned Projects below*) to use spatial analyses to understand the drivers of coral cover and health.

Five Year Plan: Over the next five years I plan to establish a globally recognized research program at a large research university. Securing a position at an institution like the Woods Hole Oceanographic Institution will allow for the recruitment of excellent graduate students and postdoctoral scholars who will develop projects, bring new perspectives, and expand the breadth of ideas that are central to my research questions. Since 2018, I have been awarded three grants (total $2.35 million) and have secured research funding for the next two years.

Major Planned Projects

1. Understanding spatial patterns of coral reef benthic class structure – Coral reef ecosystems are increasingly under threat from a variety of local to global scale stressors. In order to identify and understand the processes associated with coral reef degradation, I will use existing aerial hyperspectral imagery acquired over the Hawaiian and NW Hawaiian Islands in 2017 to produce maps of coral reef benthic class cover (coral, sand, 5 classes of algae). Potential classification models will be trained and validated using field measurements I collected at the time of image acquisition (>250 photo orthomosaics [20m x 5m transects] and benthic reflectance spectra transects acquired using SCUBA across five islands). Spatial patterns of coral reef benthic class cover types (spatial autocorrelation) will be determined and compared to reef structure, depth, and several environmental and anthropogenic stressors. This work will also prepare researchers for the immediate use of imagery from NASA's hyperspectral satellite mission planned for the mid-2020's.

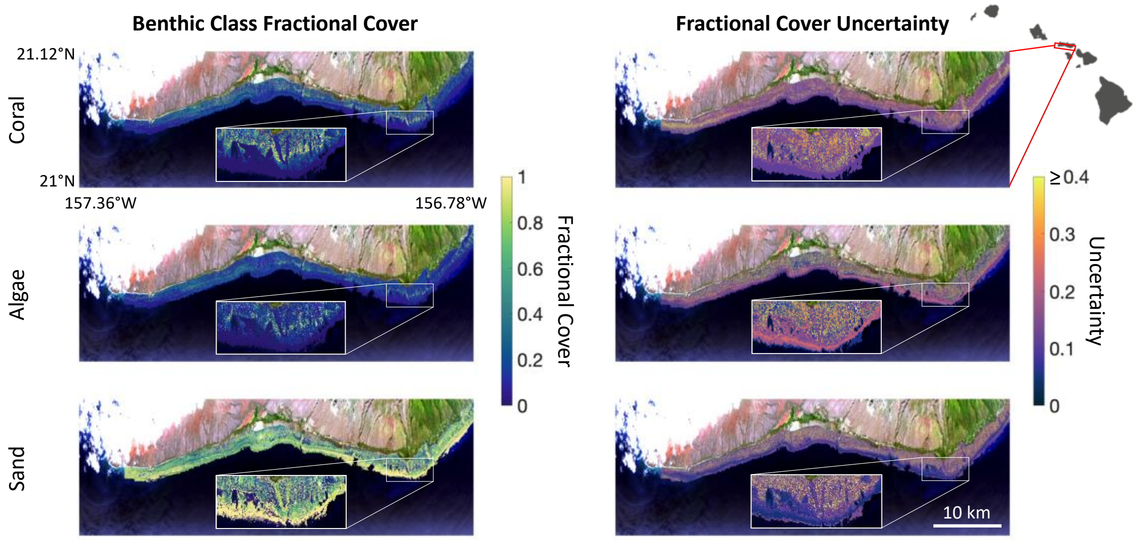

Fig. 2. Preliminary analysis of coral reef benthic class fractional cover and estimated uncertainty which will underpin the analysis proposed in *Planned Project #1*. Benthic class fractional cover of coral, algae, and sand from aerial hyperspectral imagery of the south coast of Molokai (January 27th, 2017). Maps of fractional cover uncertainty for each benthic class were derived using water property values (depth, sediment, chlorophyll) estimated from the imagery and the analysis in Bell et al. 2020.

2. A global understanding of kelp forest dynamics and local adaptation – Recent articles have discussed a global decline in kelp forest systems. However, our analysis of kelp forests in California showed that kelp, while dynamic, has been stable over the past 35 years, and that the probability of finding a significant trend is dependent on the time length/spatial scale of the study[4]. Using our automated image processing protocol and Google Earth Engine, I will develop a global dataset of kelp canopy dynamics from 1984 – present. With these data I propose to examine the response of kelp forests to interannual variability in nutrient inputs tied to decadal marine climate oscillations. Using the California kelp canopy time series, we have identified a variable response to seawater nitrate concentrations across space which may be evidence of local adaptation (**Fig. S8**). There is likely a larger latitudinal pattern to be examined once the dataset is expanded. The first paper from the project will examine the response of giant kelp and bull kelp to the anomalous warming event in 2014 ('The Blob') as a function of distance to each species' southern range limit. The Nature Conservancy has verbally committed to funding this project through at least 2023.

3. Development of monitoring solutions for coastal ecosystems – Building off my current grant from the US Dept. Energy, I will continue to develop an innovative and efficient monitoring system to quantify ecological dynamics in coastal ecosystems. As part of the project, we are training and refining deep learning models to track the growth of kelp in aquaculture farms using color cameras on autonomous underwater vehicles (**Fig. S9**). We are also using various sUAS mounted sensors to develop algorithms to examine spatiotemporal patterns of kelp cover, physiology, and age demographics (**Fig. S10**). I am looking forward to adapting these techniques to local systems to increase the spatial and temporal scale of regular and on-demand ecosystem monitoring at very high resolutions.