Imagers as Environmental Sensors
Scaling from Organism to Landscape

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Plants respond to their local climate

The responses of plants to their environment can be used as sensitive indicators of a changing climate.

Plant responses include changes in the timing of:

- Leaf production in the spring.
- Flower production.
- Leaf drop in the fall.
- Growth rates.

All these are observable phenomena, if we have the enough observers watching and recording…
Cameras are our year-round observers

Image analysis from stationary and mobile cameras can be used to quantify plant responses to climate and climate change.

Plant activity can be captured by cameras placed specifically in ecological areas or in other areas for other purposes.

From one plant to many plants
- Quality of images in natural settings
- Using color to extract information

From one camera to many cameras
- Different ecosystems
- Webcams and remote sensing
Cameras placed in different ecosystems allow us to scale our observations spatially, observing how different areas respond to climate and climate change.

However, as we expand the number of cameras, we increase the need for automatic image quality measurements and corrections.
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Time (hour of day)

![7:00 am Image](image1)

![11:00 am Image](image2)

![Graph 1](graph1)

![Graph 2](graph2)
To maximize the time available for image capture, automatic measurement of light is made, starting image capture after a threshold is reached.

Quality Measures:
- Signal / Noise
- Contrast
- Luminance

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Automatic Settings in the Dark

Exposure or Gain settings affect how the CCD signal is amplified, independent of the shutter speed or iris settings (which may also be automatic).

When light is low, automatic settings tend to prefer faster shutter speeds (to avoid motion blur) and higher amplification, resulting in grainy, noisy images with color artifacts.

Control over shutter speed and iris allows us to resume capture high quality data.
We can record the timing and duration of leaf-out in spring.
Cactus growth occurs on selected stems, often after rain events but not always.

Capturing stem growth for *Opuntia* over 34 days was a lucky result of taking photos from about 100 pan-tilt-zoom positions per day.
How do we quantify leaf out?
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Isolating plant parts based on their color
Lots of color models used for segmenting images:

- Normalized Red-Green-Blue (R / (R + G + B), etc)
- Hue-Saturation-Luminance
- Y-x-y (from CIE X Y Z)
- CIE L*a*b
- Red minus Green (R – G)
- Red divided by Green (R / G)
- Excess Green (2 * Green – Red – Blue)
- Normalized Difference Index ((G – R) / (G + R))
- i1-i2-i3 (agricultural linear transform)

And algebraic combinations of just the above results in about 54 color space components to test.
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Wallflower

Rhododendron

"Excess Red"

"Excess Green"

"Excess Blue"

Pixel value (0 - 255)
Using Principal Component and Linear Discriminant Analyses, we can visualize various color spaces occupied by leaves (green) and background (brown) and try to find the best methods to separate them for future automatic segmentation.
Hand vs. Camera for leaf area measurements
Some plant events are relatively predictable…
We know that Ceanothus will bloom in May and that Wallflowers will bloom even earlier (and last longer) and bracken ferns are like clockwork.
Some plant events are not so predictable...cameras can thus capture plant events that humans aren’t always prepared for.

Rain only at the right times of year trigger massive blooms in the desert.

At Agave Hill, the desert shrub *Encelia* spent almost 2 years without blooming, but we were finally rewarded with a brief but spectacular show.
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Soil surface temperature tracks air temperature in the shade but rises sharply because of solar radiation.

Sunflecks in the forest understory create heterogeneous patterns of soil heating that can be captured with a camera and modeled with the easily measured parameters of air temperature and solar radiation.
Roadway and scenic webcams capture images from across the US
Over 14,000 webcam images captured twice daily...
Camera # 824 has a nice view, and is also a nice example of “green-up” during spring using simple, whole-image, color (“excess green”) averaging.
Fitting a double-sigmoid curve to the data allows us to determine two points of inflection that can be compared to remote sensing estimates for the dates of spring and fall.
Dates of the inception of spring calculated from camera data is correlated with latitude.

When images are masked to include only deciduous vegetation, then the correlation is stronger compared with images masked to include only evergreen vegetation.
We are now extracting pixel information for Normalized Difference Vegetation Index (NDVI) from Modis satellite data for all the locations where we have cameras.

NDIV can correspond nicely to the ground-based camera data. Because the satellite data integrates 250 m on a side and the camera images can be masked to include or exclude types of vegetation better than Modis data.
Current and New Directions

We are working on several aspects of image processing applied to ecological imaging:

• Hardware control for High Dynamic Range imaging to extract more information during image capture of spatial patterns of summer annuals in a James Reserve meadow.

• More sophisticated image segmentation routines for separating similarly-colored plants in the same frame.

• Correlating MODIS data quality measures with quality of ground-based images.