

National Arboretum Phenomic Sensor Array (PESA) NextGen ecosystem monitoring



Tim Brown, PhD

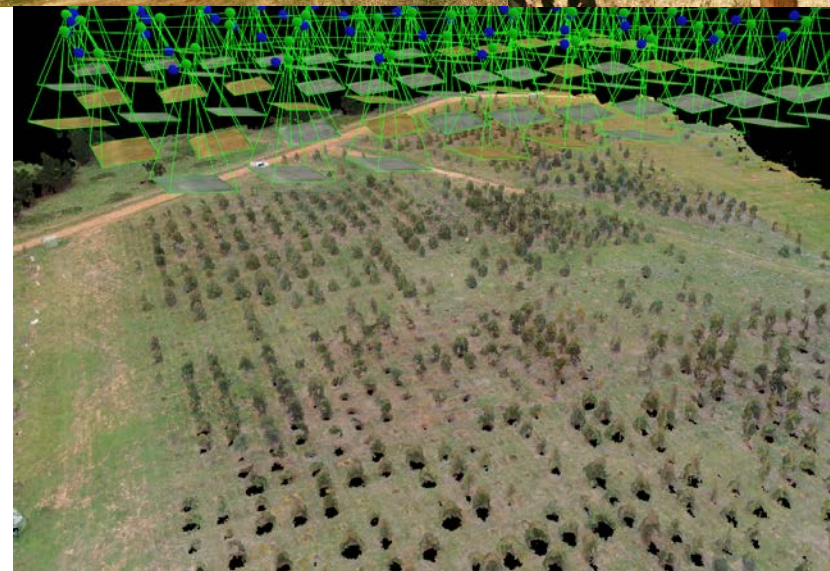
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PESA Project

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In the next 100 years we will face challenges of unprecedented scale and complexity

- Massive Biodiversity loss (since 1500):
 - ~30% decline in land animals; ~70% of invertebrates (insects, etc.) show >45% declines⁴
 - > 90% of the world's fish stocks are fully exploited or overexploited⁶
- *11 billion people on the planet by 2100*¹
- We must grow more food by 2100 than ***all the food*** produced in human history²
- Global climate will warm by 4-6°C by 2100
 - No one under the age of 24 has lived in a year when the earth was cooler than any time in the last 2,000 years
- 53% of Eucalyptus species will be out of their native ranges 2100²
- Sea levels will rise by 0.5 – 1.1m³

1) Gerland, et al, 2014, [DOI:10.1126/science.1257469];

2) "Seeds of Doubt" New Yorker, Aug 25, 2014

3) Hughes et al. Global Ecology and Biogeography Letters (1996): 23-29.

4) "Climate Change Risks to Australia's Coast", 2009

5) Dirzo, Rodolfo, et al. 2014. DOI: 10.1126/science.1251817

6) <http://worldoceanreview.com/en/wor-2/fisheries/state-of-fisheries-worldwide/>

The grand challenge of the 21st century

Sustain and create ecosystems that

- optimize benefit to other living things
- provide sustainable ecosystem services for humans
- in the face of **over-population, resource scarcity, climate change** and other major negative humans impacts

We no longer have the luxury of trusting low resolution ecological models

Traditionally field ecology has had very limited capacity

- Low spatial/time resolution data
- Limited sensors other than weather
- Sampling is manual; subjective
- Observations not-interoperable
 - Limited data sharing
 - Few standards
- Repeat experiments: often *different sites; different observers; different methods*



**What % of data from the last century of ecology is available for reuse?
(even your own data)**

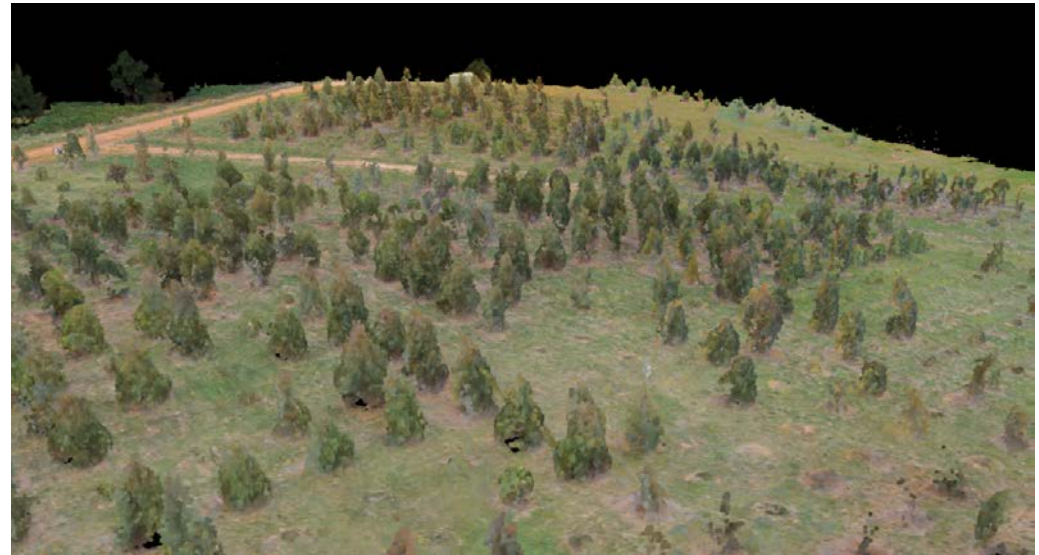
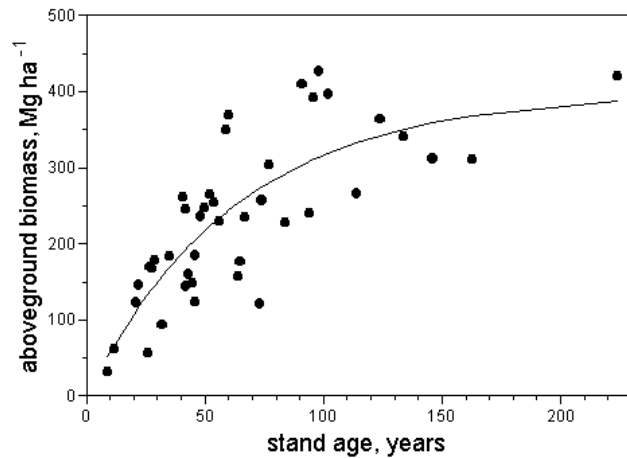
Monitoring “Everything all the time”

How to do improve field ecology datasets

1. Large, long-term regional-scale monitoring projects
 - TERN/Supersites; NEON, ICOS; FLUXNET, etc
 - Standardized high-quality data products for long periods of time
 - Force development of standard methods and data standards
 - Provide large, well-curated public datasets that we can all use
2. Data standards (more on this later)
 - If our data isn't interoperable its utility is very limited
3. Capture higher complexity data
 - New technology is changing everything and will revolutionize how we do ecology

The challenge

- Persistent 3D, multi data-layer ecosystem model



Lab Phenomics – Monitoring “everything all the time”

Genotype X Environment = Phenotypes (heritable traits)

Understanding how Phenotype, Environment and Genetics interact in plants requires:

- mm resolution 5-min timescale 3D models of each plant growing
- Multi/hyperspectral imaging
- Fluorescence scanning to measure photosynthesis
- Thermal scans (respiration, water use efficiency, etc)
- Control lighting and temperature to mimic real world growth conditions

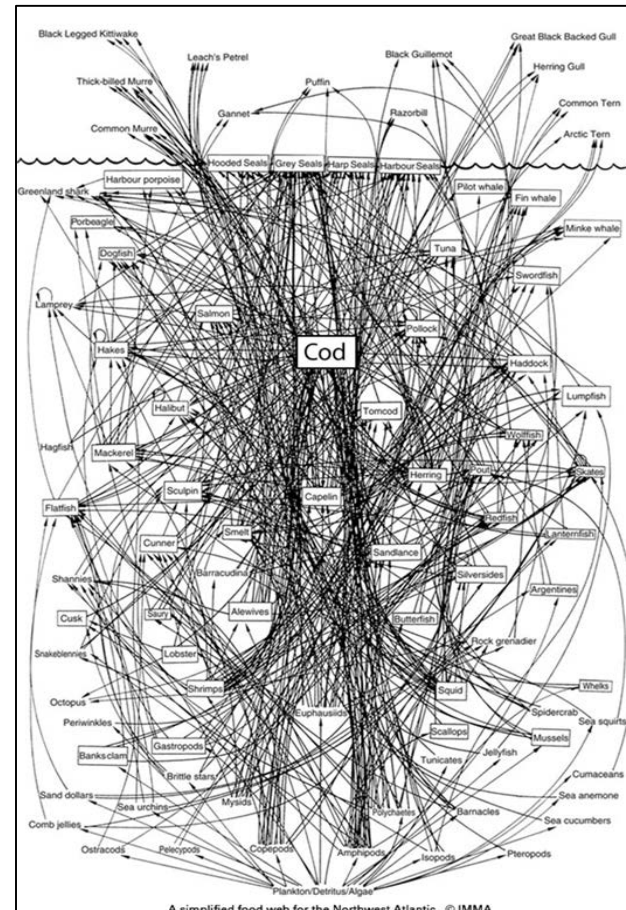
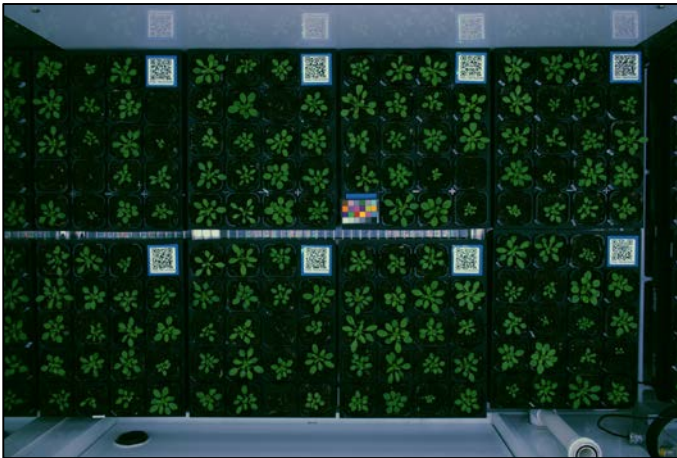
Requires contrived environments



The real world is way more complex than plants in the lab

Don't we need equally complex datasets and models to understand real world ecosystems?

- This hasn't traditionally been possible
- The questions we ask are often defined more by what data we can get than by what the best question would be
- What questions would you ask if you had a 10-year high-resolution dataset of your field site?



“NextGen” monitoring

Within ten years we will have similar data to lab phenomics

- Automated time-series (weekly/daily) aerial (UAV) scans measure:
 - RGB; Hyperspectral; Thermal; (lidar?)
 - Centimeter resolution 3D model of every tree on field site
- Gigapixel imaging to track phenology in every tree/plant
 - Automated computer visions analysis for change detection
- LIDAR scanning
 - DWEL / Zebedee – high resolution 3D scans (ground based)
 - Dense point clouds of 3D structure
- Microclimate sensor networks
 - PAR
 - Temp, Humidity
 - Soil moisture @ multiple depths
 - mm resolution dendrometers
- Full genome for every tree on site (<\$5/tree)

Phenotype

Environment

Genetics

New technology is changing everything

We should all aspire to build field sites that last 10,20,30 years

Looking back that far...

- 30 years ago was ~1980 (everything was analog)
 - The first space shuttle (1981) **1MB** of RAM¹ (your phone has 2000x this)
 - 4G is the same bandwidth that MODIS uses to download a full satellite image of the earth every day (MODIS: 6.1Mbps avg; Verizon 4G: 5-12Mbps ^{2,3})
- Even 20 years ago: no Web, WiFi, cell phones, Google anything
- **1.8 billion** (mostly geolocated) images are uploaded to social media every day (4)
- Consider: 75% of cars may be self-driving by 2040⁵ – continuously imaging, laser scanning and 3D modelling their immediate environment: 6.2 billion miles⁶ of roadside environments in US, imaged in 3D daily!

1. <http://www.popsoci.com/node/31716>

2. <http://modis.gsfc.nasa.gov/about/specifications.php>

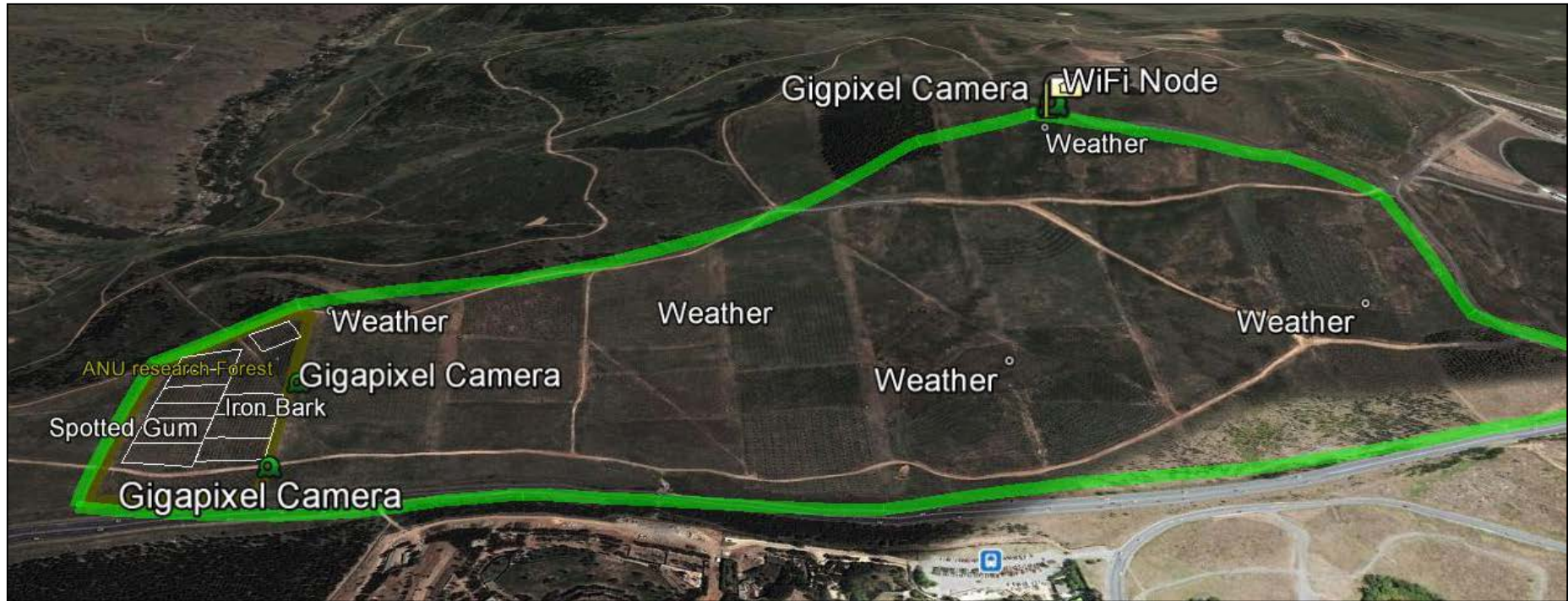
3. <https://www.lte.vzw.com/AboutLTE/VerizonWirelessLTENetwork/tabid/6003/Default.aspx>

4. [Meeker, 2014](#)

5. http://www.ieee.org/about/news/2012/5september_2_2012.html

6. http://www.fhwa.dot.gov/policyinformation/travel_monitoring/13dectvt/figure1.cfm

National Arboretum Phenomic & Environmental Sensor Array



ANU Major Equipment Grant, 2014

Collaboration with
Cris Brack, Albert Van Dijk (Fenner school) and Borevitz Lab

National Arboretum Phenomic & Environmental Sensor Array

- Ideal location
 - 5km from ANU (64 Mbps wifi)
- Many institutions close by
 - ANU, CSIRO, U. Canberra , etc
- Brand new forest to monitor from birth into the future
- Great test site for “NextGen” monitoring prior to more remote deployment



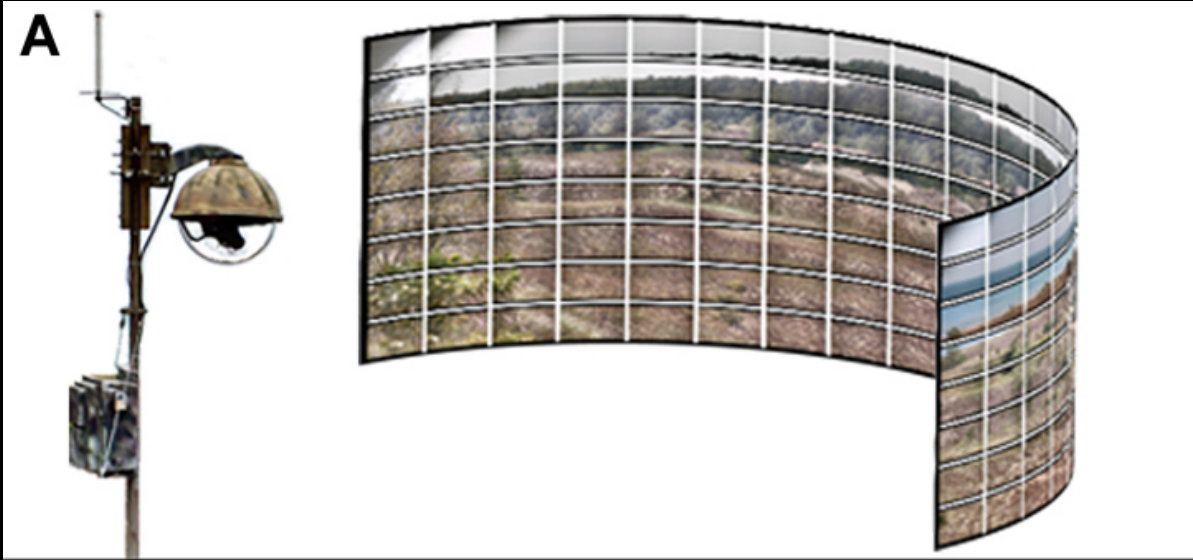
National Arboretum Sensor Array

- 20-node Wireless mesh sensor network (Temp, Hum, PAR, Soil T/M)
- High resolution dendrometers on 20 trees
- Two Gigapixel timelapse cameras:
 - Leaf/growth phenology for > 1,000 trees
- Campbell weather stations (baseline data for verification)
- All data live online in realtime
- LIDAR: DWEL / Zebedee
- UAV overflights (bi-weekly/monthly)
 - Georectified Google Earth/GIS image layers
 - High resolution DEM
 - 3D point cloud of site in time-series

Demo Video

- <http://youtu.be/fBf9RUatu3o>

Gigapixel Imaging – How it works



The Gigapan and Gigavision systems allow you to capture hundreds or thousands of zoomed-in images in a panorama.

Images are then “Stitched” into a seamless panorama.

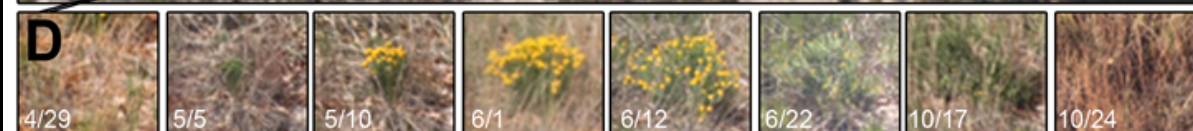
(Single 15MP image)



Area: ~7ha



The super-high resolution of the final panorama lets you monitor huge landscape areas in great detail.



Area: ~1m²

Gigavision: Open source gigapixel time-lapse camera



- 2008 - TimeScience (my company) & U Chicago (Borevitz Lab)
- Capture timelapse of every leaf on every tree within a few hectares
- ~250MP to 3 billion pixels / panorama (~600 million * MODIS resolution)
- Solar powered; wireless/cellular
- Demo at Gigavision.org



Current work:

- Open source software on Raspberry PI (\$35 computer) enable standard PTZ cameras to be gigapixel timelapse cameras
- Cloud solution for data processing -> Post-processing is online (automatic)
 - < \$6,000 for complete wifi, solar gigapixel system
- *Data management and extraction are a challenge*

Unmanned Aerial Systems (UAV/UAS)

- This is the future of ecosystem monitoring!
- Tech is very new and changing at light speed
 - Getting much easier & cheaper VERY quickly
- Current regs are restrictive
- But anyone can get started now for ~\$1,000



DJI Phantom Vision 2+

\$1,500 AUD

*VERY easy autopilot control via
Pix4D and DJI phone apps*



Pocket Drone: \$450

20min flight time

GoPro Mount

Control with tablet



Droidworx Hexacopter
~\$5K AUD



Sensefly.com, ~\$25K



Gatewing (Trimble), ~\$90,000



So what do we do with all this data?

The challenge is no longer to gather the data, the challenge is how we do science with the data once we have it

- A sample is no longer a data point

- Example: Gigavision data

From Sample:

- Camera hardware: 1200 images (per hour)
- Automate stitching into panoramas (5,000 tiles images / pano /hr)
- Need to align time-series images to each other and to the real world (despite hardware failures, camera upgrades)
- How to visualize a time-series of 22 million images/year?
- Computer vision analysis
 - Automated feature detection and phenophase detections

To Data:

- “Phenophase” transition and growth data from 1,000 trees
- *And then how do you even analyze that?!*

Big data doesn't work without data standards

- **Data management and synthesis** is essential to doing science in the 21st century
- **New technology** *lets* us measure the world in *unprecedented detail* but it *creates so much data* we have to *organize it better*
- **Data standards** allow us to share and collaborate with our data in ways never before possible
- How will people access your data?
- When you publish a paper, it should have a DOI with a link to the code you used and the data you analyzed
 - Aspire to: Readers can redo your analysis on their desktops

- What questions can our collective data help answer?
- Coverage
 - What are we monitoring well now?
 - What are the gaps?
 - Sensors/ data types
 - Spatial coverage
 - Data availability / incompatibility
- Data standards
 - What are the barriers to sharing data and what can we do to facilitate data sharing?
- New technology will completely change the resolution at which we can monitor the environment
 - What questions would you ask/answer if you could know anything from your field site back for a decade?
 - What new tools do we need to do science with these new data types?

Thanks and Contacts

- Funding: ANU Major Equipment Grant
- Cris Brack, Albert VanDijk, Justin Borevitz (PESA Project PI's)
- Project web page
 - <http://bit.ly/PESA2014>
- Collaborators
 - UAV data: Darrell Burkey, ProUAV
 - 3D site modelling: Pix4D.com
 - Dendrometers & site infrastructure
 - Darius Culvenor: *Environmental Sensing Systems*
 - Mesh sensors: EnviroStatus, Alberta, CA



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