Eco-evolutionary Data Across Time to Infer Biodiversity Dynamics

Acute relevance of biodiversity data across diverse disciplines & sectors ......

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Collections in Biodiversity Dynamics

Museum specimens for understanding change - Museum collections provide physical record of environments – both past and present
**Grinnell Resurvey**
**MVZ, UC Berkeley**

**Tamias alpinus** Alpine Chipmunk
- High elevation specialist
- Range contracted at lower limit
- Reduced genetic diversity in modern era.

**Tamias speciosus** Lodgepole Chipmunk
- Overlaps with *T. alpinus* at upper range limit.
- No change in elevational range
- Current genetic diversity is the same as in historic era.

Genomics, isotopes and pollen: California bees

Carbon ($d^{13}C$) and Nitrogen ($d^{15}N$) of Honey Bees over time

Reconstructing historical ecological interactions by identifying pollen on preserved bees.

Tracking the impacts of ecological, climate, and land use change by quantifying stable isotope ratios.

Analysis of historical collections to document how honey bees, native bees, plants, and pollination activities have changed over the last ~100 years in response to urbanization, agricultural land conversion, etc.

T. Dawson, Julie Truong (2012, unpubl)
But for most organisms, we have no information from the past
• For many, we have no information even of identity
• How, then, do we understand response to change?

First, do we really need to?
The Insect Apocalypse Is Here
What does it mean for the rest of life on Earth?
UN Report: 1 Million Animal And Plant Species At Risk Of Extinction

GrrlScientist Contributor ○
Science
Evolutionary & behavioural ecologist, ornithologist & science writer

Loss of biodiversity is just as catastrophic as climate change

Robert Watson

Nature is being eroded at rates unprecedented in human history but we still have time to stave off mass extinctions

Biodiversity loss accelerates with 1 million species at risk of extinction, UN report finds

Seth Borenstein, Associated Press

Half of all amphibian species are likely facing extinction, adding to biodiversity threat
Threats to the world’s ecosystems ... complex mix of habitat destruction, climate change, disease, invasive species....

- No reliable way to quantify the overall health of an ecosystem.
- Much needed are metrics that encapsulate the “status” of the biological component of an ecosystem and allows comparison across space and time, yet is agnostic to species identity.
Islands allow development & testing of these ideas
Signatures of ecosystem change through time –
*Using islands as microcosms to test theory*
Provide a time series

By Rob Gamesby
http://www.coolgeography.co.uk
Information on organisms over gradients of space & time

Biodiversity dynamics

Fitness

Immigration Extinction

Species richness

Rates
Islands are also disproportionately impacted by anthropogenic influences
• Harbingers of what can be expected globally
Ginger Invasion!

Waikamoi Preserve, Maui, March 2015
Photo: Kari Goodman
Auwahi, Maui – “museum forest”

http://www.auwahi.org
Auwahi, Maui – recovery

Photo: Art Medeiros

http://www.auwahi.org
Two advances
• Empirical data – metabarcoding.
• Integrative and predictive theoretical framework.
Together, these approaches can be used for
  – Biodiversity forecasting
    • Abundance distributions
    • Networks
Linking back to specimens is then essential to understand the process!

Can use these island systems to ......

• Identify “functionality”
• “Robustness” or resilience
How to get “signatures” of community ……

Looking at sites of similar elevation, precipitation; all in *Metrosideros* forest

Across sites that vary in age alone

Community Dynamics Across a Chronosequence
How to get “signatures” of community …..

Across sites that vary in elevation/precipitation

Community Dynamics Across a Chronosequence
Signatures of Community Status

Identity & abundance

- Kingdom
- Phylum
- Class
- Order
- Family
- Genus
- Species

Networks & interactions

Invasion impact & vulnerability
Community Assembly Across the Chronosequence

Changes in Community Structure & Dynamics

Henrik Krehenwinkel
Trier University
Problems with Metabarcoding

- Need information on
  - Abundance - abundance distributions can provide information on the “status” of a community
  - Identity of species in the sample

Abundance

Multilocus amplification bias

Krehenwinkel …. & Gillespie. 2017 Scientific Reports. 7, 17668
Abundance

PCR amplification bias

Krehenwinkel .... & Gillespie. 2017 *Scientific Reports*. 7, 17668
Signatures of Community Status

Identity & abundance of all members

Network & interactions

Invasion impact & vulnerability

Kingdom
Phylum
Class
Order
Family
Genus
Species

[Diagram showing network and interactions among different species and organisms]

[Image of a globe with various species and insects]

[Image of a dense community of insects and microorganisms]
Maximum Entropy Theory of Ecology

- Community-wide genetic divergence across space, environment and time (chronosequence)
- Testing novel theory

Fitting species abundance data to METE predictions

Deviation from predictions on youngest substrates may indicate that community has not yet reached steady state

- Allows identification of non steady state community
- Does not inform us on the cause

Rominger et al. 2015 Global Ecology and Biogeography
Signatures of Community Status

Identity & abundance of all members

Network & interactions

Invasion impact & vulnerability
Interactions

Changes in Community Structure & Dynamics

- Plant 1
  - Size 0-2
  - Amplicon 1
- Plant 2
  - Size 2-4
  - Amplicon 2
- Plant 3
  - Size 4-7
- Plant 4
  - Size >7
- Plant N
  - ~10 arthropod samples by plant

~80 forest sites

Data structure

Henrik Krehenwinkel
Trier University
Interactions

- Genetic structure of entire community of interacting lineages in the ecosystem
- What factors drive divergence of lineages?
Changes in Network Structure Across the Chronosequence

To understand the processes, need the identity of the players
Signatures of Community Status

Identity & abundance of all members

Networks & interactions

Invasion impact & vulnerability
Elevational community turnover

- Stainbeck
- Laupahoehoe
- > 500,000 years

Beta diversity vs. Elevation distance

Young ▶️ Old
Ranges Occupied on Younger vs Older Sites

Prediction: younger sites more easily invaded

Younger substrates – broader range, less specialized

Order:
- Acari
- Coleoptera
- Lepidoptera
- Orthoptera
- Araneae
- Hemiptera
- Neuroptera
- Pscooptera

Mean annual temperature range

Mean annual rainfall range

Site:
- Laupahoehoe
- Stainback
Collembolan invasions

44% of all arthropods on average
Invasive Collembola Across Chronosequence

Proportion in a given sample

Preliminary inference: Biotic resilience
Identifying Non Natives?

PIGS .....  MELASTOMES

BANANA POKA

GUAVA

GOATS

FROGS

ANTS .....  GINGER
417 Hawaiian arthropod specimens from 12 orders

Categorization of species as native or non-native using DNA sequence signatures without a complete reference library

Signatures of evolution over the geological chronosequence very different from signatures of invasive species

Andersen et al., 2019.
Evolutionary Applications, in press
Can we understand our own biology soon enough to make a difference?

Barnosky et al. (2012) *Nature*
• Metrics derived from network structure can indicate resilience, resistance, and response
• However, to take action, we need to identify the players
On Borneo for a 2018 expedition to find new species, evolutionary biologist Marta Paterno of the University of Verona in Italy prepares samples for a portable DNA sequencer (center, right of laptop). PIERRE ESCOUBAS/TAXON EXPEDITIONS 2018

$180 million DNA ‘barcode’ project aims to discover 2 million new species

By Elizabeth Pennisi | Jun. 6, 2019, 2:00 PM

For centuries biologists have identified new species at a painstakingly slow pace, describing specimens’ physical features and other defining traits, and often trying to fit a species into the tree of life before naming and publishing it. Now, they have begun to determine whether a specimen is likely a novel species, which is the first step toward naming a new species.
Collections in Biodiversity Dynamics

Signatures of ecosystem change through time
– *Using islands as microcosms to test theory*

Highlights the tremendous **relevance** and largely untapped **potential** of collections in providing signatures of ecosystem **resilience, resistance, and response to change**

And the relevance goes far beyond biology …..
Fire season in most places used to be about 2 months; now it has lengthened up to 5 in places, or even the full year.

Higher temperatures & drought create ideal conditions for wildfires.

Dry weather means more dead trees, shrubs, & grass, and more fuel for the fire.

Plants that like humidity are replaced by more flammable plants that withstand dry conditions.

Water stressed trees send down deep roots to suck up every drop of water, further drying out the soil.

Warm weather causes wood beetles from south moving north, killing tree parts & increasing amount of flammable material.

Warmer temperatures can trigger more lightening, which can set blazes.

Burning forests release stored carbon into the atmosphere, contributing to global warming.

Climate change boosts the intensity of fires; heightened intensity neutralizes efforts to put out the blaze.
Agri-food ecosystem template

Four principle components
- ecosystem functions, climate, resource inputs
- key actors and external influences
- environmental and health penalties
- losses and wastes
Collections in Biodiversity Dynamics

• The biodiversity crisis is real and will affect every aspect of human existence
• Collections – both historic and current - provide the key to understanding resilience, resistance, and response to change
• Most important now is to communicate the relevance before it is too late
Thanks – A team effort!

Understanding network structure & tipping points

Global Synergies & Sustainability for Biodiversity Information

Combining forces with efforts across other Pacific Islands