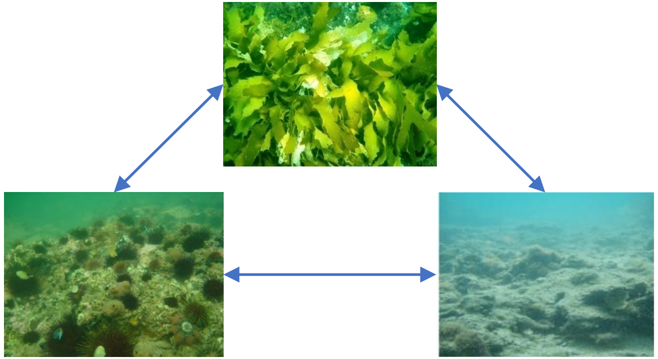
Understanding Cause and Consequence of Change in Benthic Marine Ecosystems



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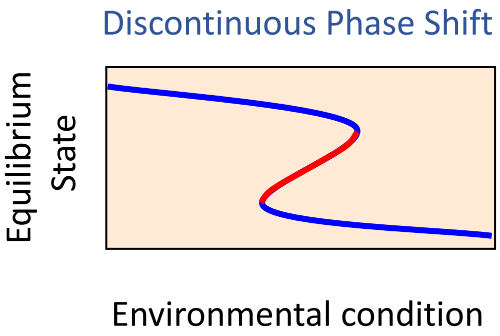
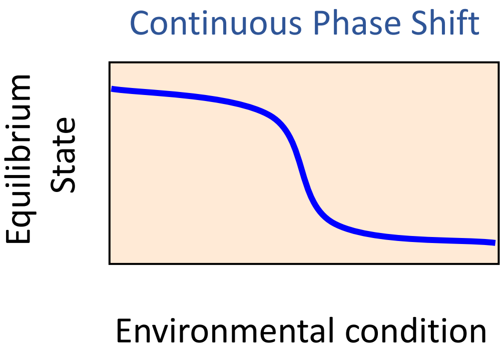
Ecologists usually view continuous and discontinuous phase shifts as mutually exclusive possibilities

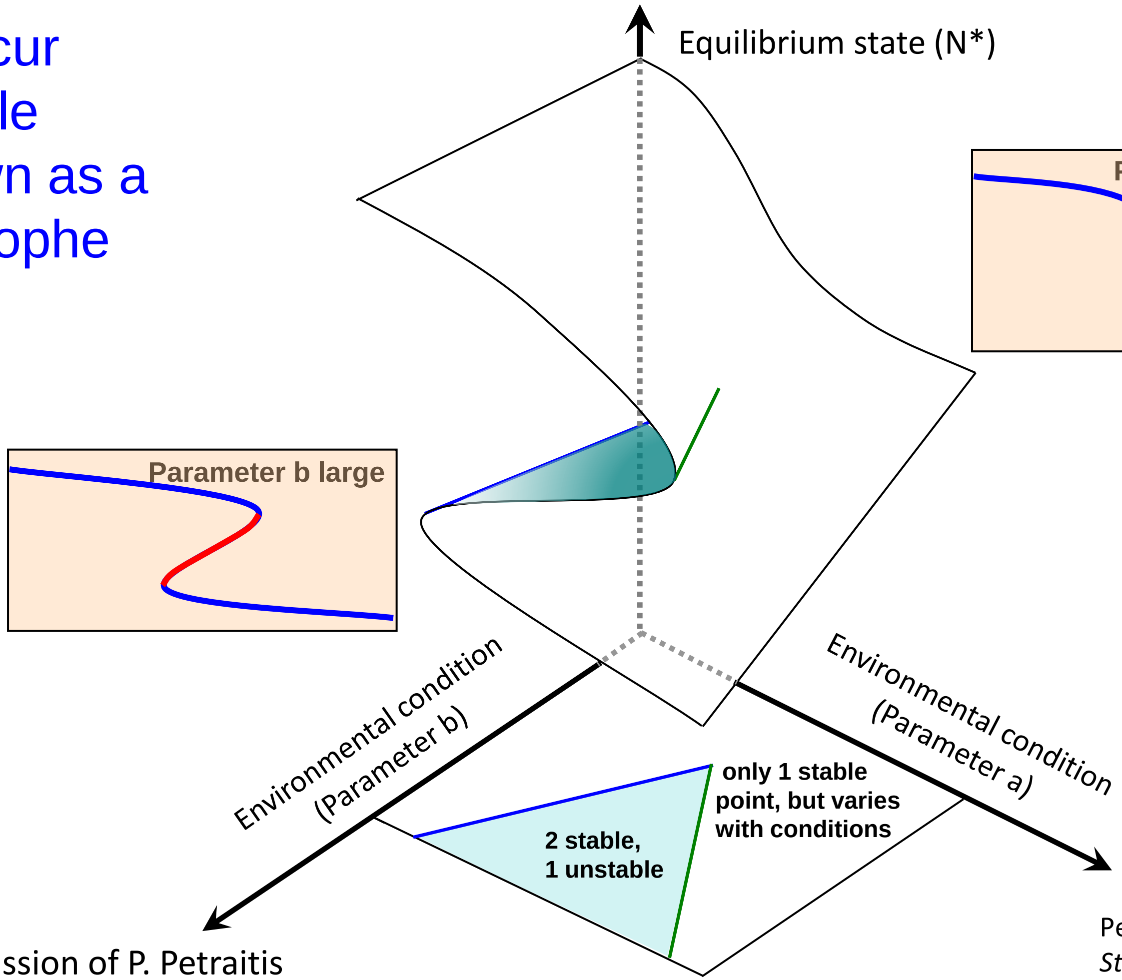




Images used with permission of P. Petraitis

Petraitis (2013) *Multiple Stable States in Natural Ecosystems*

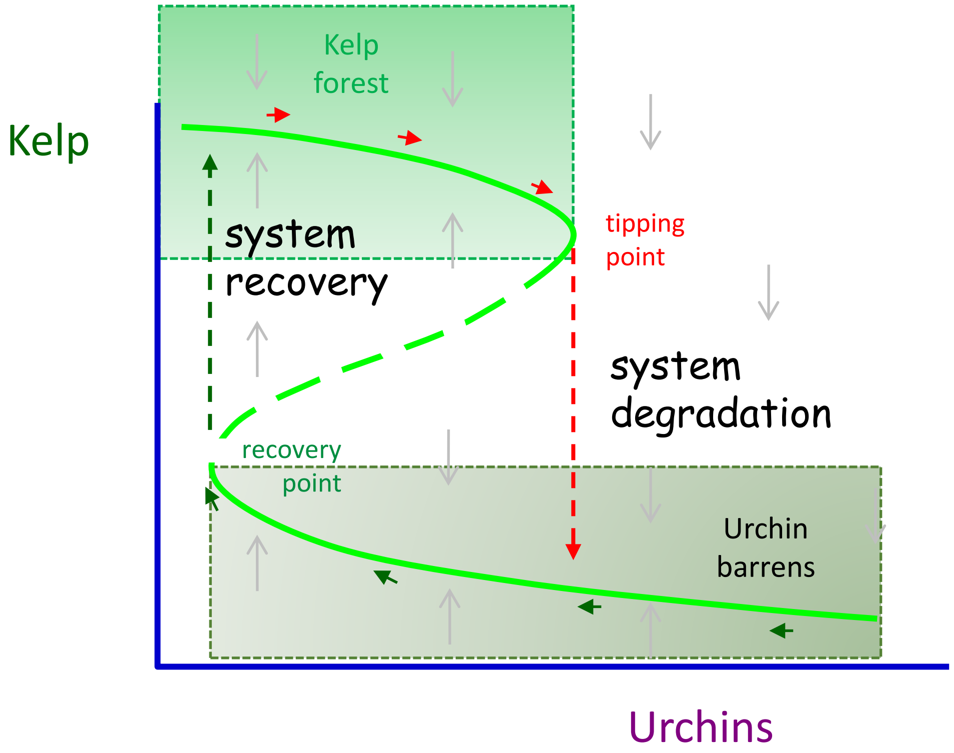
Both can occur within a single model; known as a cusp catastrophe



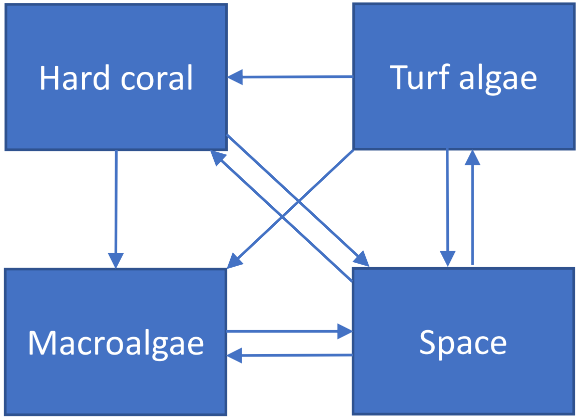
Images used with permission of P. Petraitis

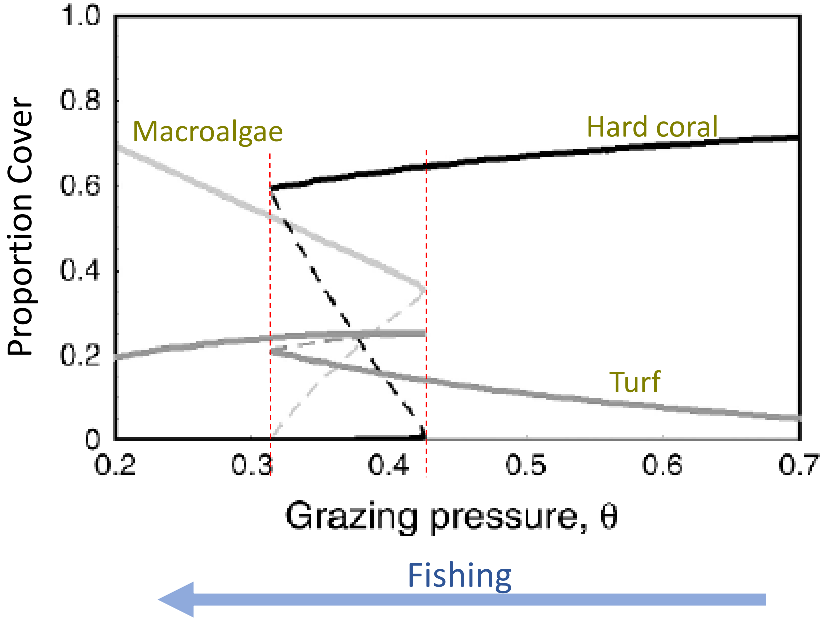
Petraitis (2013) *Multiple Stable States in Natural Ecosystems*

Discontinuous phase shift can represent large challenges for management



Models reveal systems with 3 alternative stable states

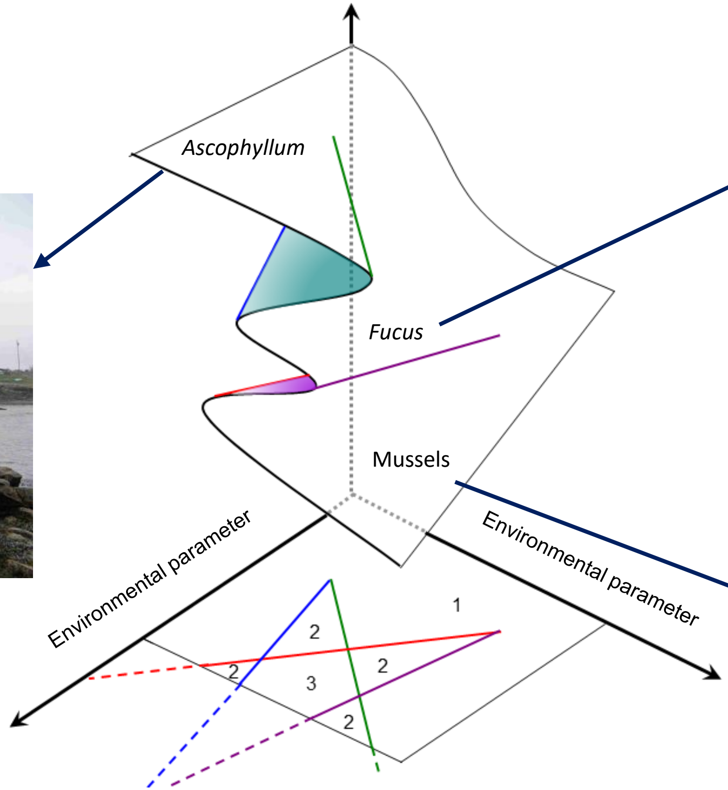




Fung, Seymour & Johnson (2011) *Ecology* 67: 967-982

The butterfly catastrophe: 1-3 stable states

Mill Pond

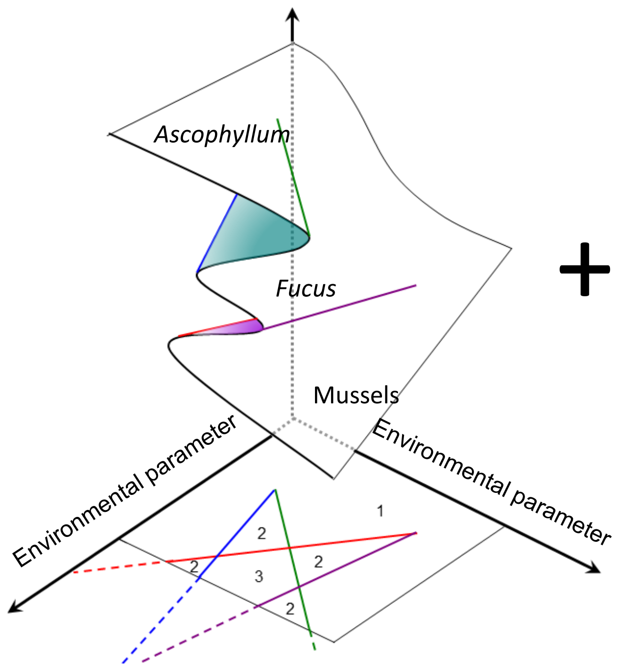


Mill Pond

Photo credits P. Petraitis

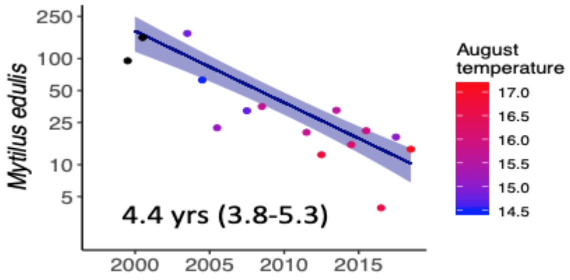
Petraitis, Methratta, Rhile, Vidargas, & Dudgeon (2009) *Oecologia* 161:139-148

A changing seascape



+

Annual Recruitment per 40 cm^2



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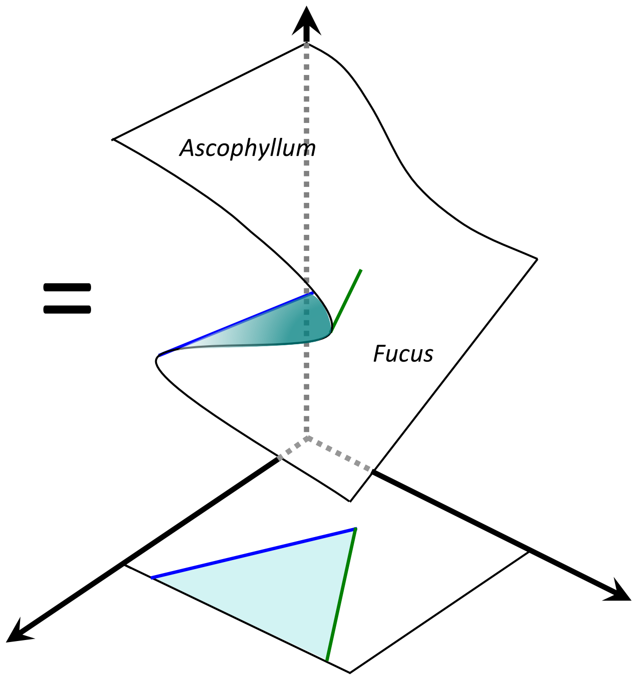
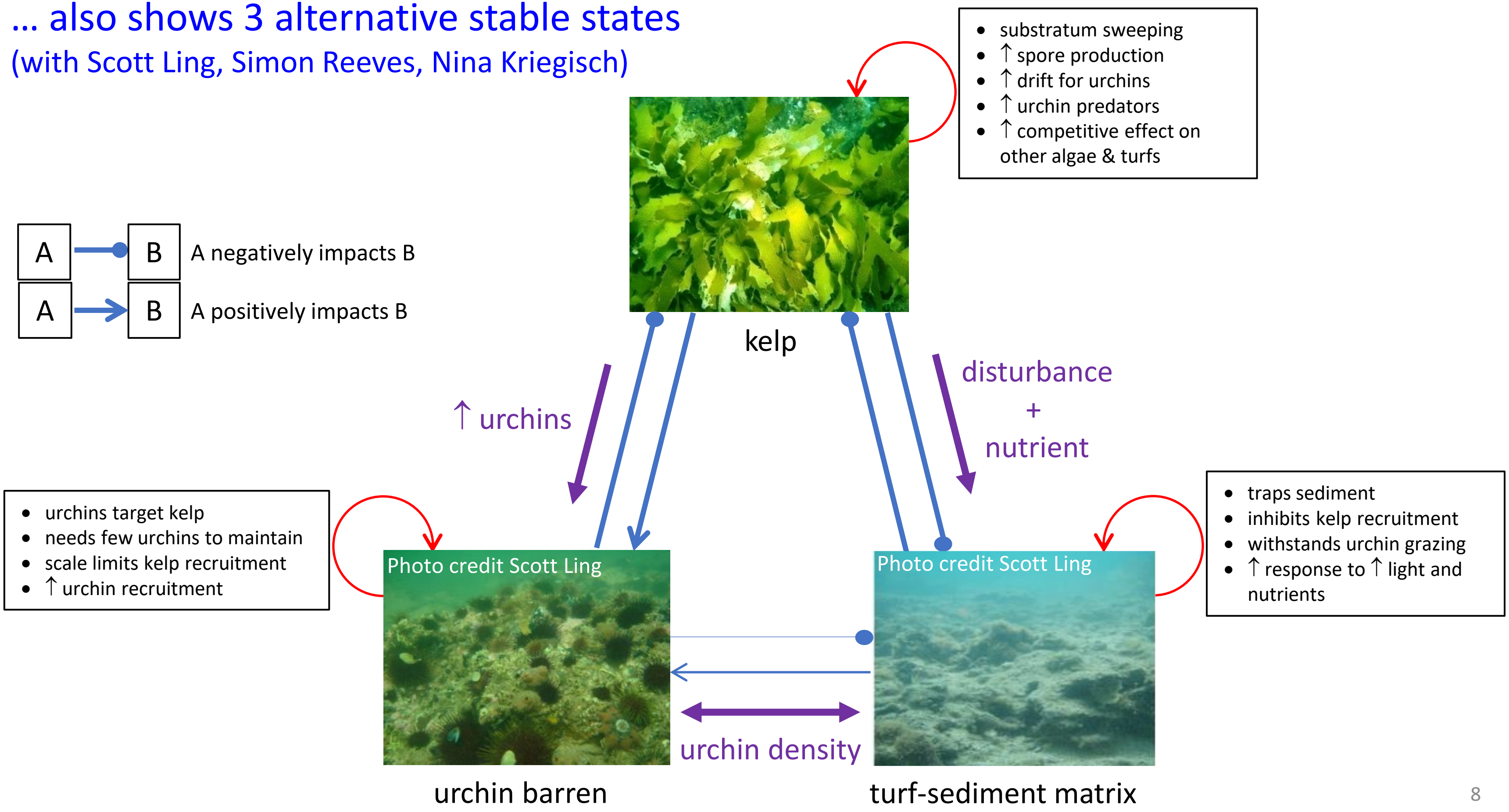


Petraitis & Dudgeon (2015) *Mar Freshwat Res* 67: 37-46
Petraitis & Dudgeon (2020) *Communications Biol* 3: 591-597

Port Phillip Bay, Victoria
… also shows 3 alternative stable states
(with Scott Ling, Simon Reeves, Nina Kriegisch)



Challenges to understanding community change

1. Distinguishing between:
    - long transient stages and stable states
    - continuous and discontinuous phase shifts

2. Early Warning Signals are not unique to discontinuous phase shifts (EWS – critical slowing down, anomalous variance, autocorrelation, non-linearity)

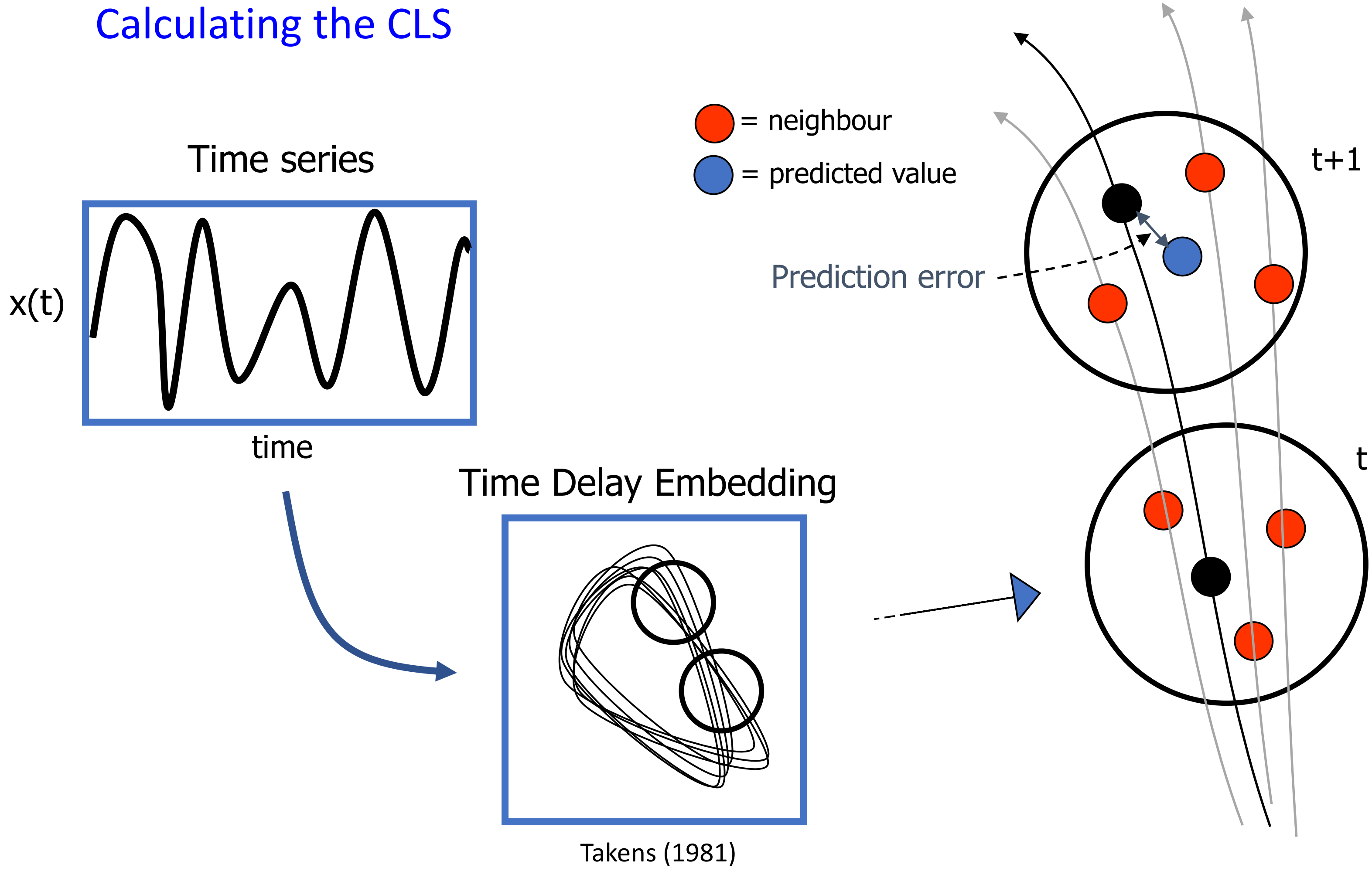
3. Occurrence of hysteresis and divergence, and predictive value of EWS, depend on environmental and system “noise” (i.e. the time convention)

4. Difficulties of measurement & interpretation (e.g. rapid shifts can occur with both phase shift types, catastrophic shifts may occur very slowly, sample sizes for EWS prohibitive)
    - how to interpret observed change? ‘normal’ fluctuation or phase shift?

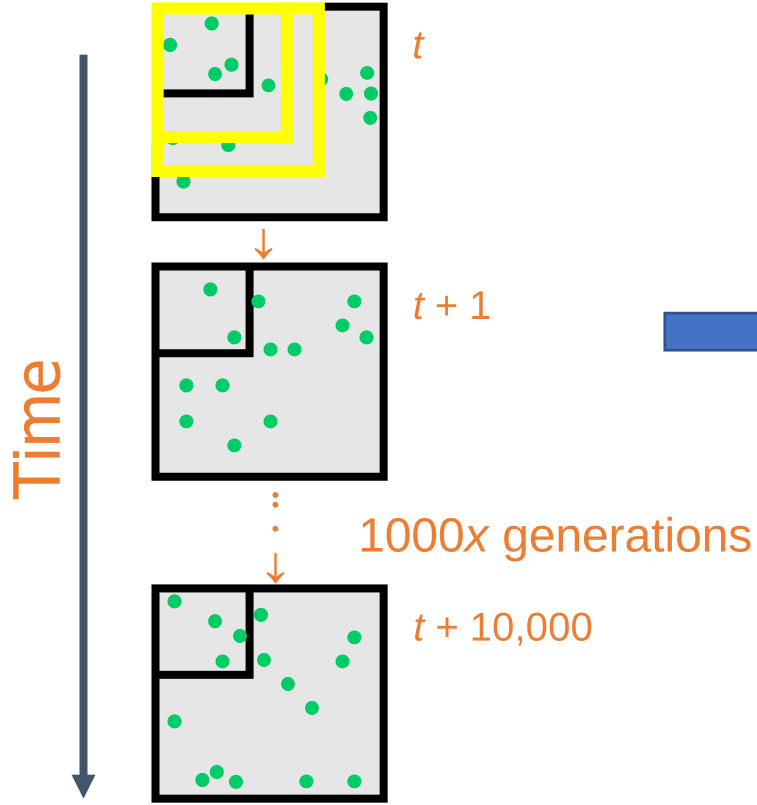
The Ecologists Conundrum: How to interpret change in community structure?

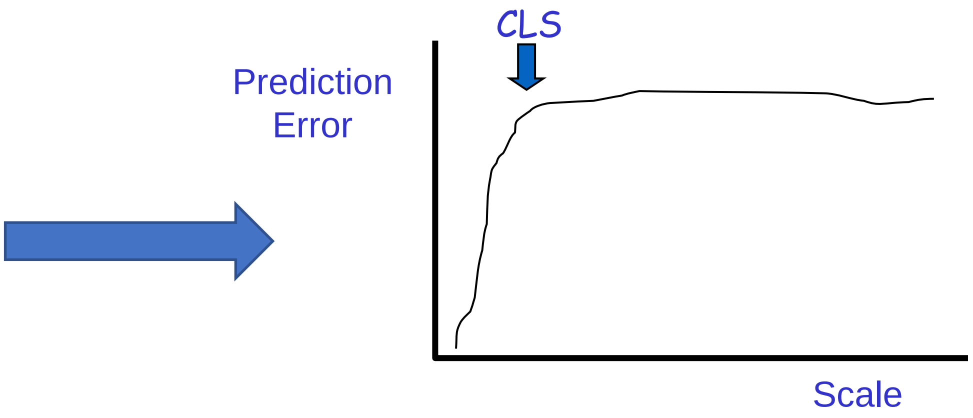
- Easy to *observe* change, but how do you *interpret* it?
- How to distinguish 'normal' fluctuations in dynamics from phase transition?
- Critical Length Scales (CLSs) appear to be a good candidate …
    - CLS can be determined from any one species in a system of interacting species
    - the CLS does not change if a system fluctuates within a single basin of attraction
    - if there is a phase shift the CLS will change
    - CLS can be calculated from 1-D (line transect) or 2-D (maps) spatial data using short time series (e.g. 3 time steps) and/or sliding windows across space (i.e. substituting space for time)

Calculating the CLS



Calculating the CLS

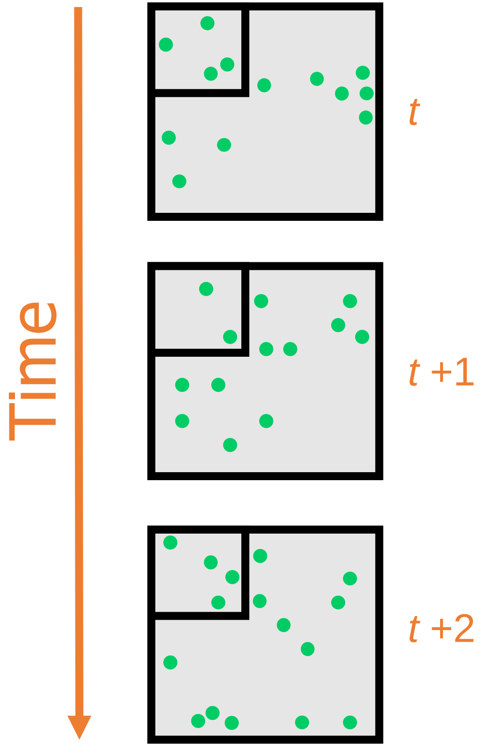




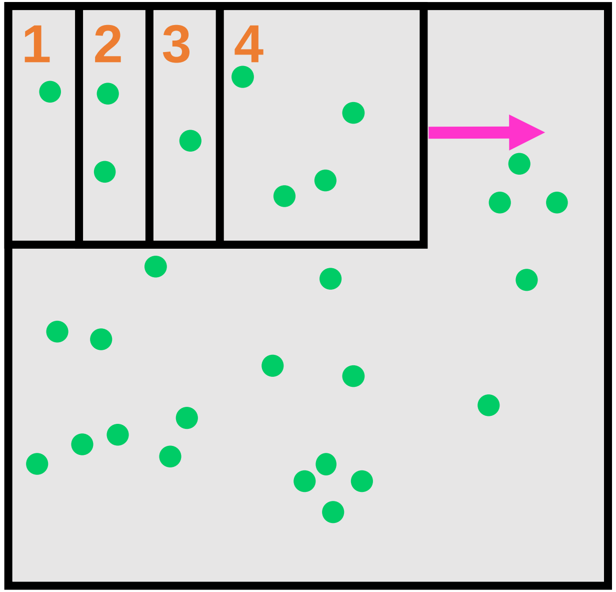
Keeling et al. (1997) *Phil Trans Royal Soc B*, 352:1589-1601
Pascual & Levin (1999) *Ecology* 80: 2225-2236

Calculating the CLS – substituting space for time to estimate the attractor

Short time series



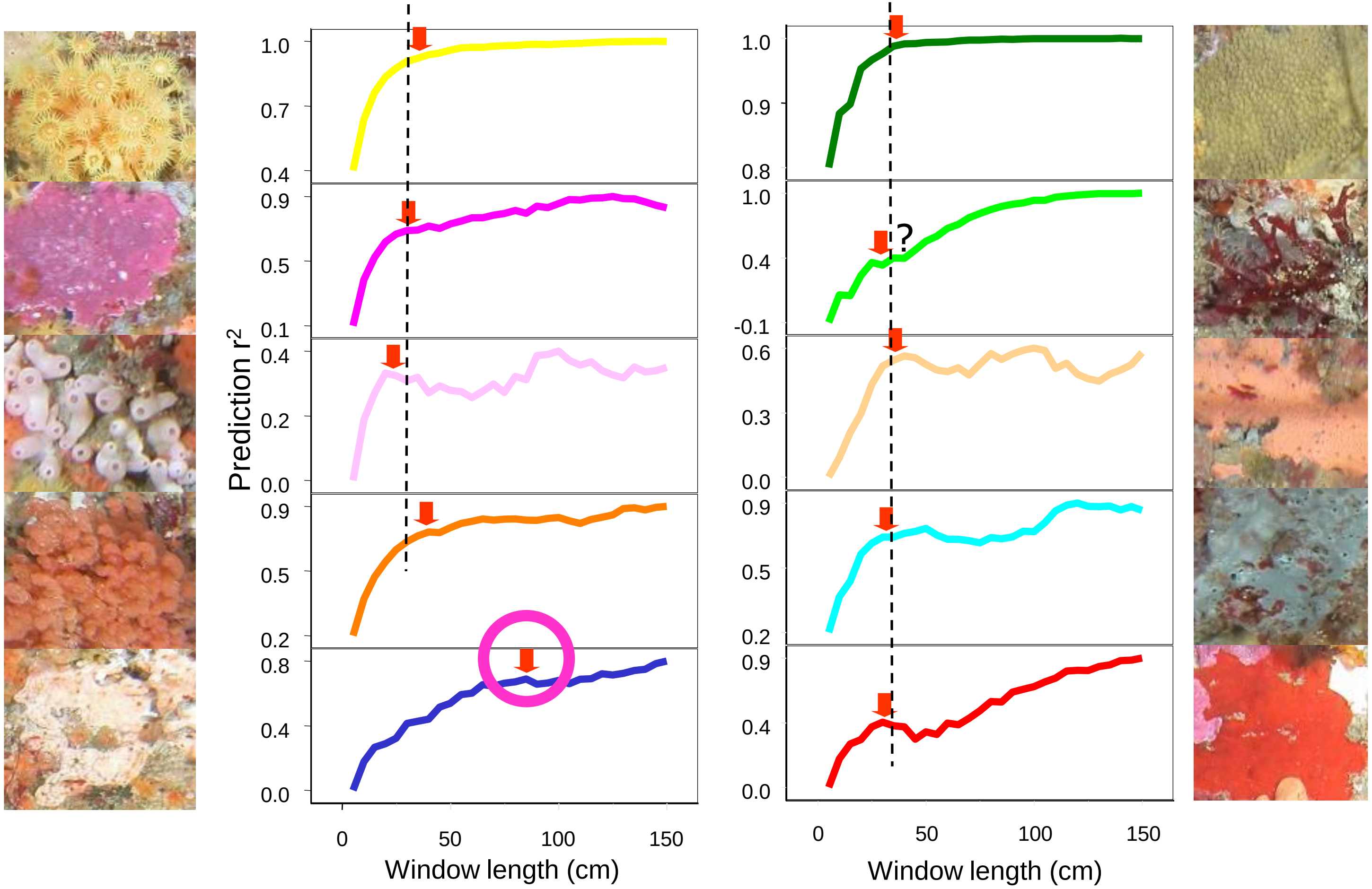
Sliding windows



Map from a single time *t*

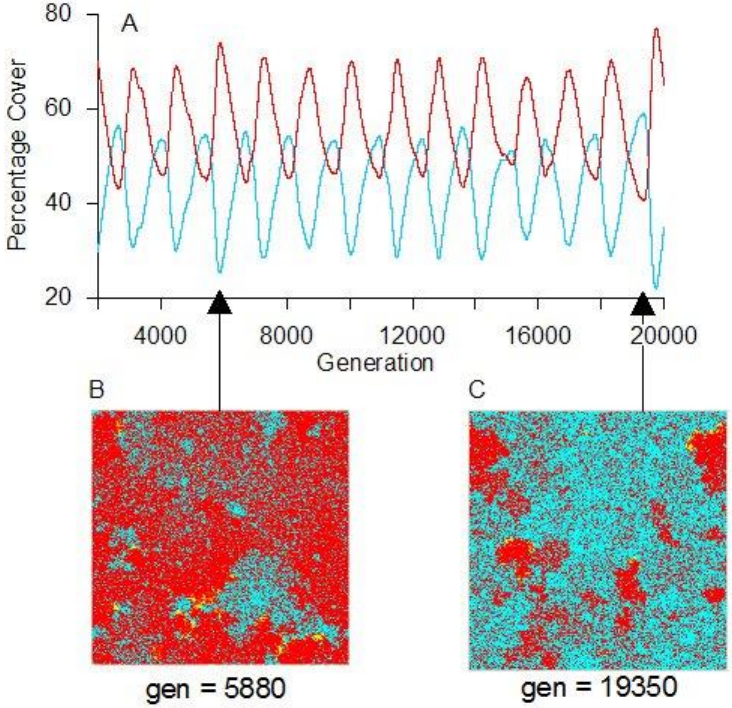
Habeeb, Trebilco, Wotherspoon & Johnson (2005) *Ecol Monogr* 75: 467-487

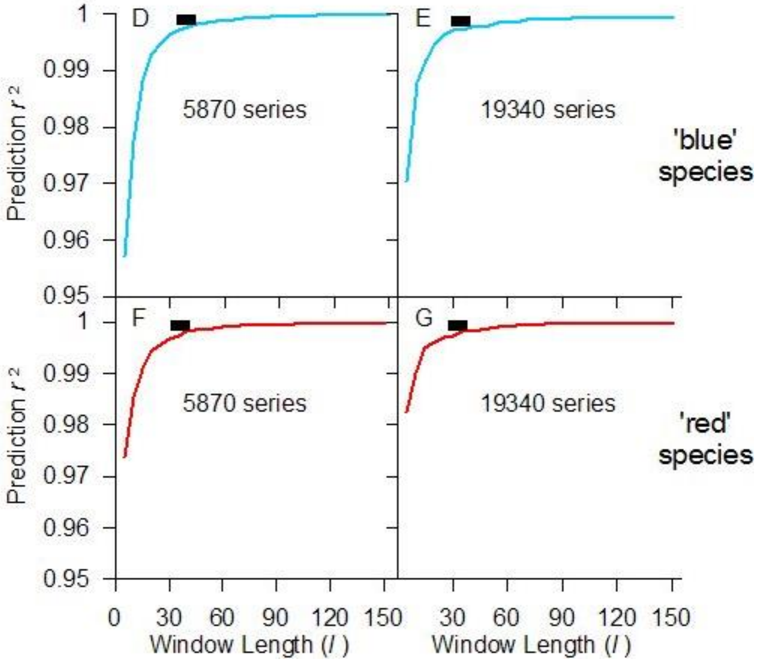
Example – subtidal rock wall community



Johnson, Chabot, Marzloff & Wotherspoon (2017) *Restoration Ecol* 25: 140-147

Model 1: Oscillating dynamics (single attractor)



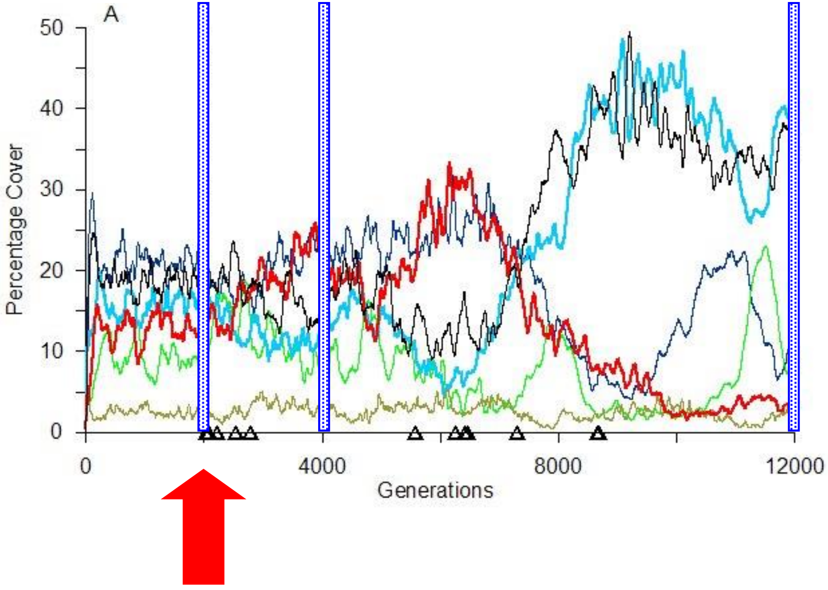


CLS constant @ ~35 units

Johnson (2009) *Ecol & Society* 14(1): 7. (21 pp)

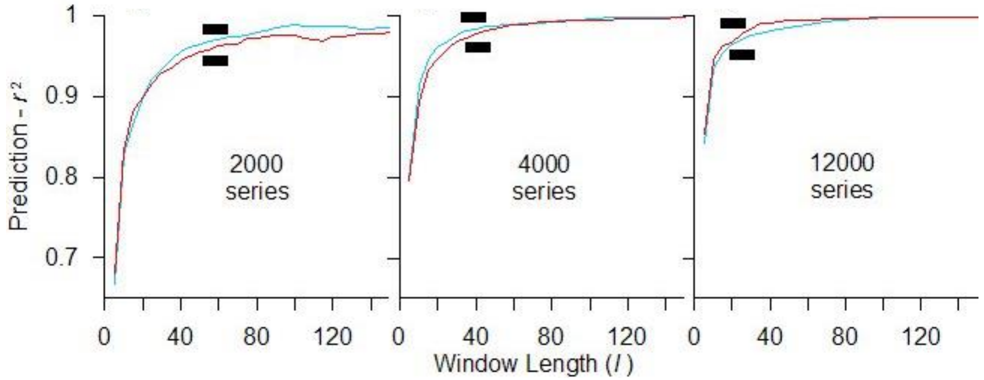
Model 2: Fundamental change in underlying dynamics (shift in attractor)

(20 species system)



‘Open’ recruitment fails

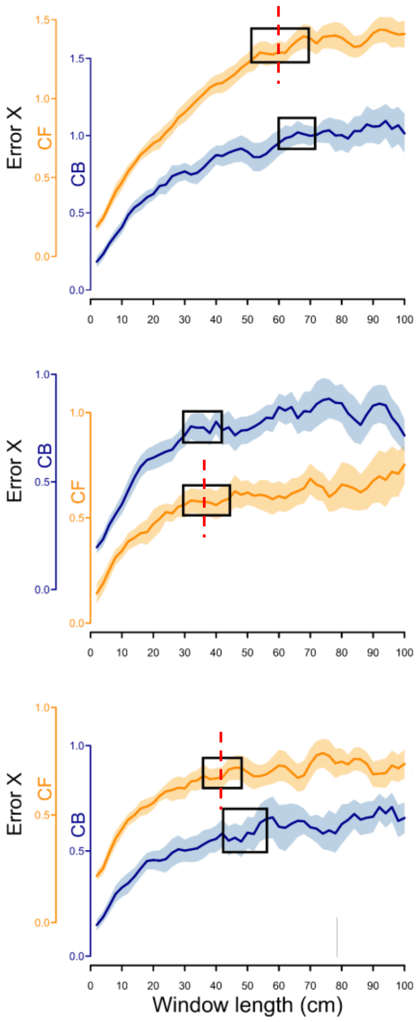
CLS drops from ~60 to ~20



Johnson (2009) *Ecol & Society* 14(1): 7. (21 pp)

Empirical example:

Coral reef community at Blue Bowl, Wakatobi Marine National Park, Sulawesi, Indonesia



foliose coral

branching coral

2007 – dominated by foliose coral

2010 – dominated by algae

2011 – dominated by algae

- CLS from 1-D line transects (60 m, 1 cm resolution)
- Transition from coral to algal dominated 2007-2010

Ward, Wotherspoon, Melbourne-Thomas, Haapkyla, Johnson (2018) *Ecol Monogr* 88: 694-715

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Thank You!
Photo credit: Justin Gilligan