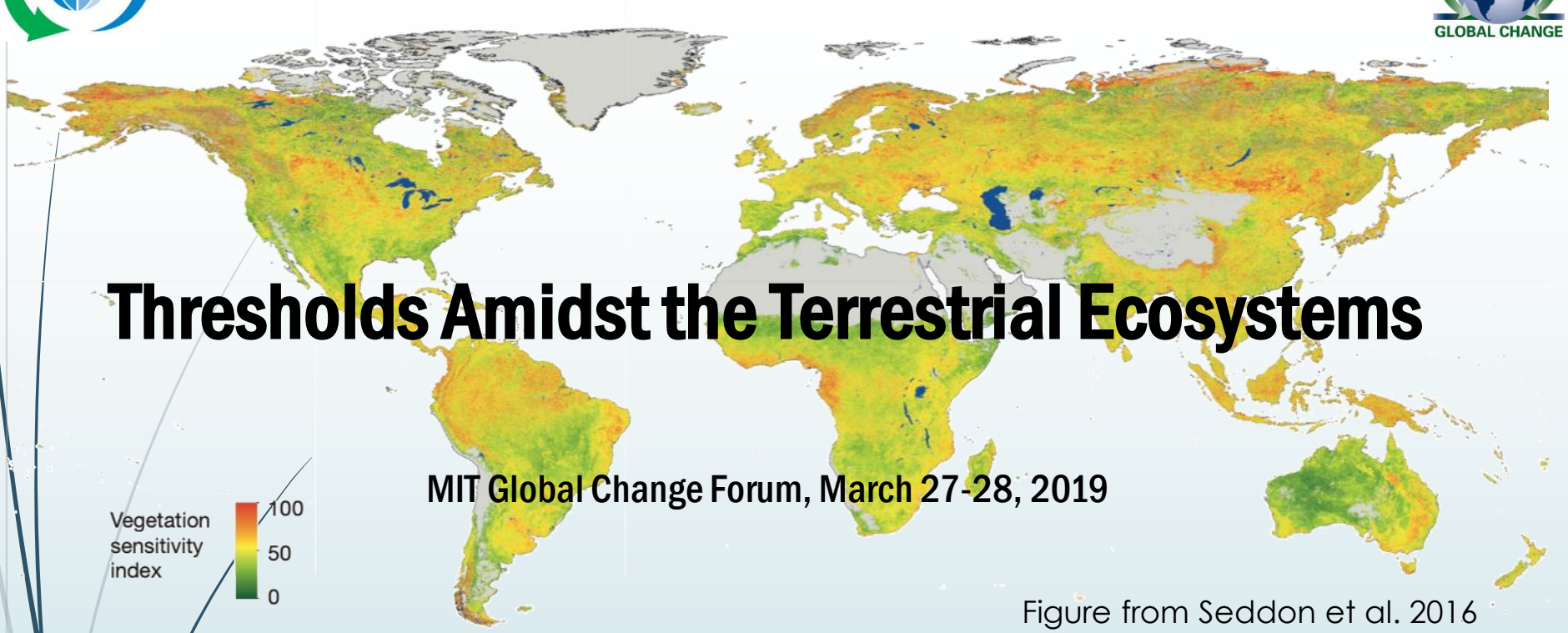
Thresholds Amidst the Terrestrial Ecosystems



MIT Global Change Forum, March 27-28, 2019

Figure from Seddon et al. 2016

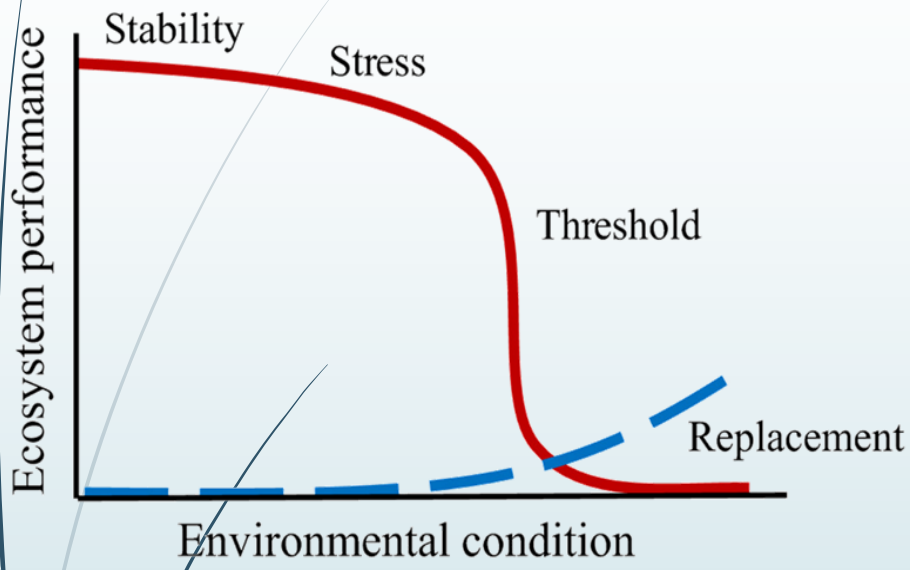
THRESHOLD: THE MAGNITUDE OR INTENSITY THAT MUST BE EXCEEDED FOR A CERTAIN REACTION, PHENOMENON, RESULT, OR CONDITION TO OCCUR.

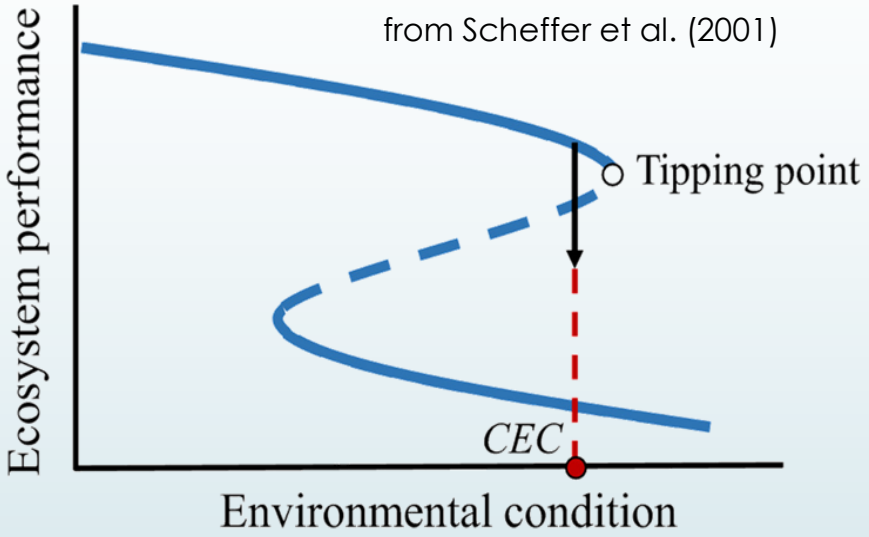
- MAXIMUM LEVEL OF RADIATION OR CONCENTRATION CONSIDERED ACCEPTABLE OR SAFE.
- LIMIT BELOW WHICH A STIMULUS CAUSES NO REACTION.
- LEVEL, RATE, OR AMOUNT AT WHICH SOMETHING COMES INTO EFFECT.

Acknowledgements: Allen et al. – USGS SAP4.2 (2009), Huggett (2005), Kelly et al. (2014), Martin et al. (2017), Munson et al. (2018), Nicotral et al. (2010), Polasky et al. (2011), Schwartz et al. (2006), Thompson (2011)

Thresholds, Tipping Points, and Critical Transitions

Sudden, nonlinear changes in the integrity or state initiated by (small changes) environmental drivers.

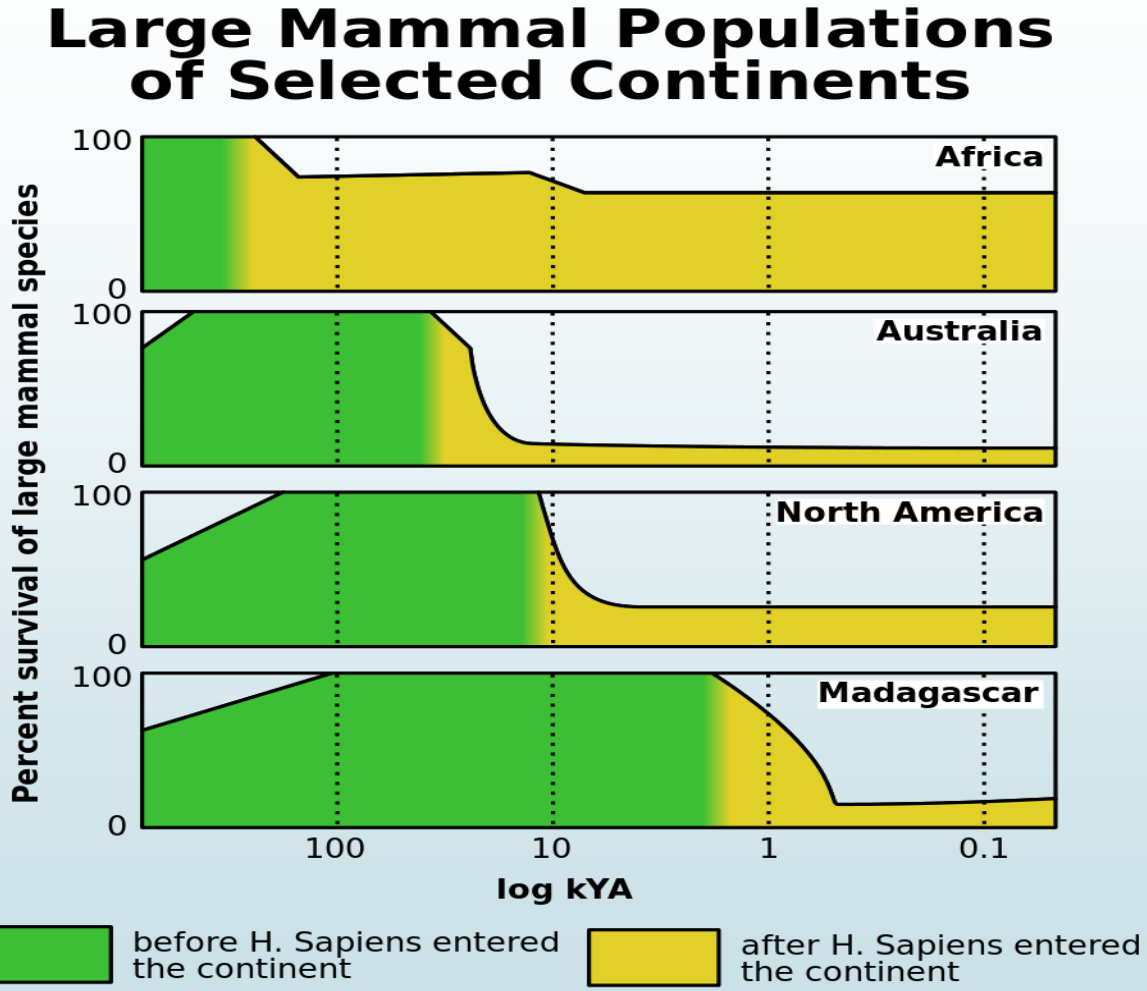




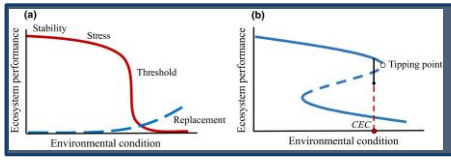
General definition: Progression from ecosystem stability, to stress, to "rapid" response, and eventually to replacement by a novel ecosystem under changing environmental conditions.

Stricter definition: Alternative states separated by an unstable equilibrium (dashed line) at a critical environmental condition (CEC) – such that returning to prior environmental conditions may not result in a previous state (at least not right away).

Homo Sapiens and Megfauna Extinctions… We Seem Threshold Capable

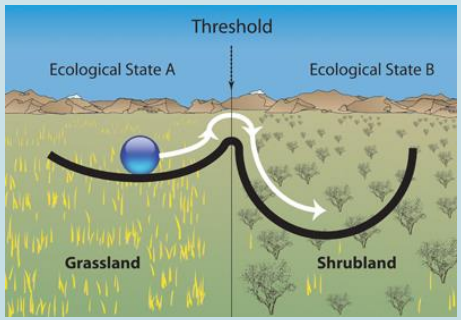


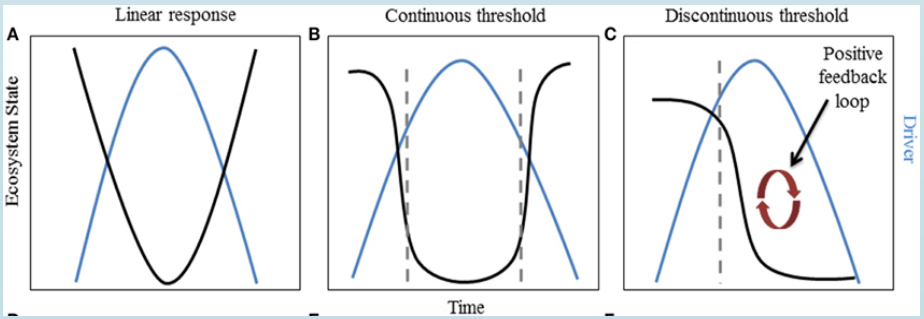
Causes of the sudden disappearance of the megafauna remains actively debated, but emergence of humans (e.g. "effective hunting technology", land use) just prior to steady decline is striking.

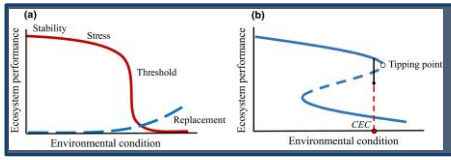


Vegetation Thresholds: Challenges, Drivers, and Metrics

- Plant systems: Complex, heterogeneous, and dynamic
- Conceptual framework is cogent: Exposure to a rate of damaging change exceeding rate at which they can adapt (adaptive plasticity), or the rate at which individuals can disperse.
- Performance tied to plant growth (e.g. basal/foliar cover, tree ring)
- Thresholds related to grazing pressure, landscape fragmentation, patch size, and connectivity.
- Extinction aside - difficult to prove that an alternative/irreversible ecosystem state has been reached.
- Need long term monitoring of informative variables – and done so in places where this has happened (or will). Hard to predict.

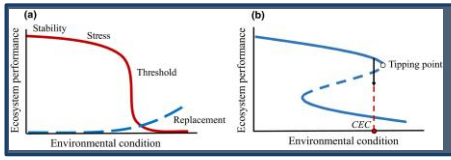






Challenges, Drivers, and Metrics

- Transitions difficult to perceive and/or detect and mechanisms responsible often unclear.
- Intra-plant structure can have independent responses to shifts environmental conditions.
- Growing occurrence of extremes – early warning? Increased attention to temperatures, drought, insects and pathogen outbreaks, permafrost thaw and uncharacteristic wildfires.
- Interactions with anthropogenic stressors, such as atmospheric pollution, land use, fire management, and invasive species.
- Precursory indications over tropical (e.g. Betts, Sanderson and Woodward, 2008; Malhi et al., 2008) and boreal

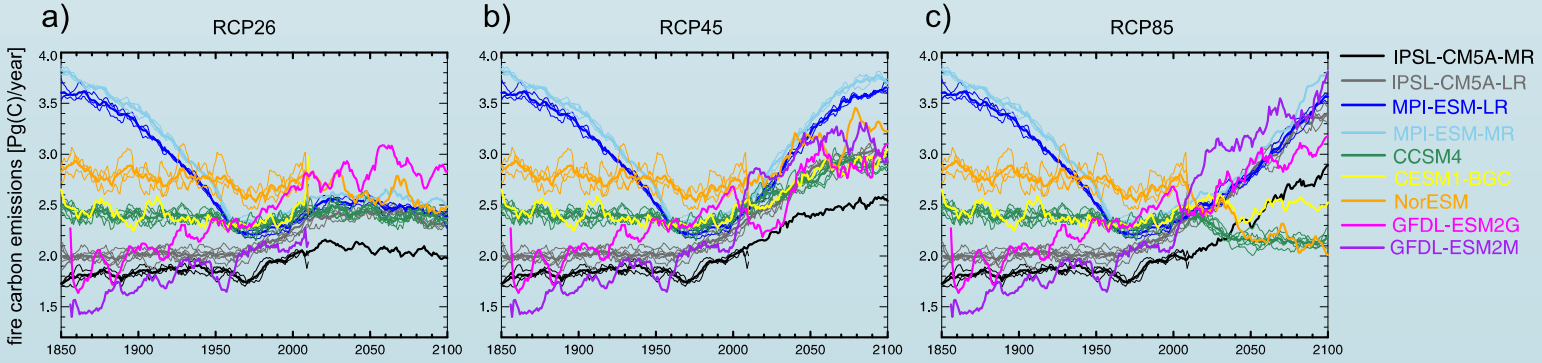


Review of Past Vegetation Changes

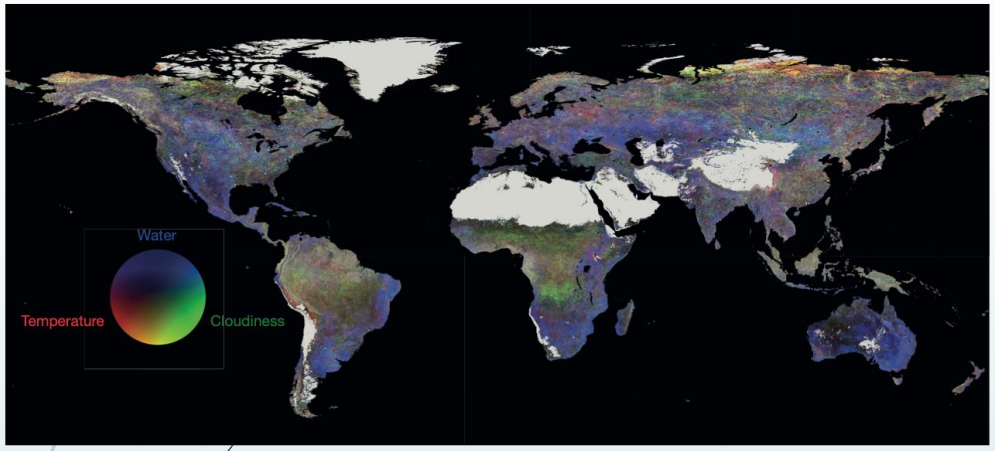
- Boreal paleorecords suggest "relatively" abrupt vegetation changes, but difficult to specify due to limited temporal resolution of records.
- Siberian vegetation changed at the Pleistocene-Holocene boundary from widespread productive steppe grassland to less productive moss/shrub tundra (Yurtsev, 2001).
- Introduction of exotic species can trigger massive alterations in the properties of a system, leading to a new stable state.
- Initial post-glacial Scandinavia vegetation showed low resilience and changed rapidly to subarctic birch forests that have been highly resilient to subsequent climatic variations.
- Dieback and positive feedbacks in a temperate forest as assessed via basal area – show importance of longevity in mature and mortality rates in juvenile trees. (Martin et al., 2017).

Fires: Now and Looking Ahead

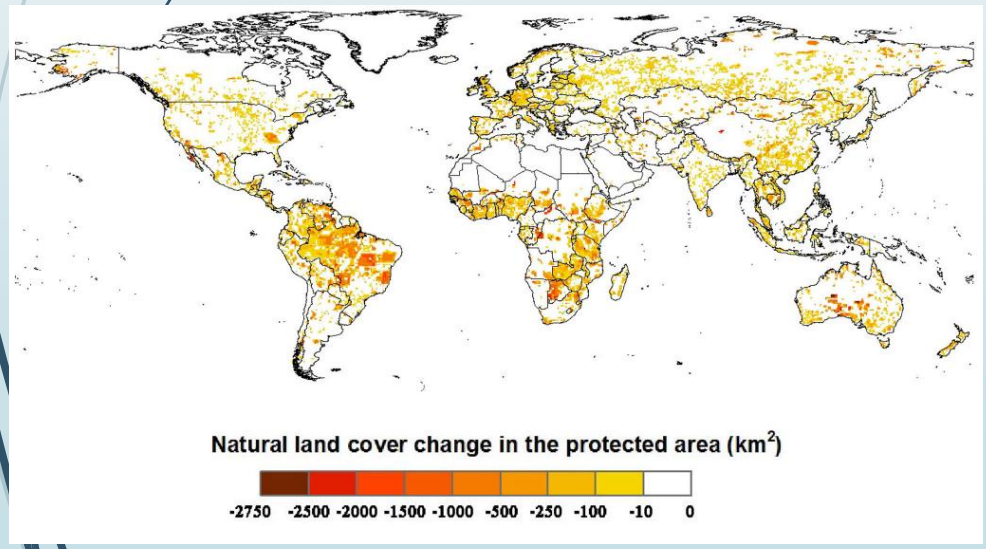
- Migration of black spruce (early Holocene) into interior Alaska coincided with increase in fire frequency. This then promoted persistence of fire-adapted black spruce (e.g. Lynch et al., 2003 and Lloyd et al., 2004).
- Boreal forests of eastern Canada: Millennial cycle in fire regimes have lead to imbalanced mosaic to current climate.
- Amazonian forests – logging, fire, regional hydroclimatic change.
- Fire suppression and invasive grasses are building up fuel. It's what people are doing to the "surface of the planet"
- Forest fires and climate change: Latest CMIP5 results showed mixed consensus of trends (Figure below from Kloster and Lasslop, 2017)



Global Assessments: Vegetation Sensitivity and Protected Land Area - A Threshold Combination?



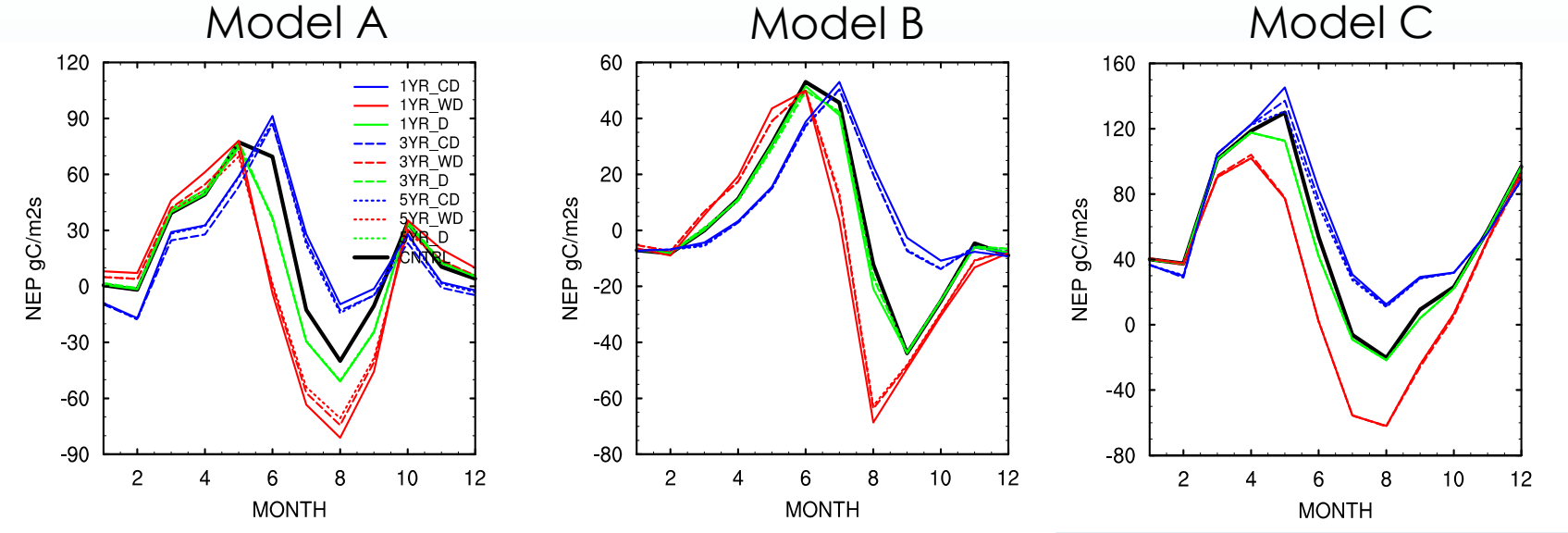
Seddon et al. 2016



Melillo et al. 2015

- MODIS-based estimates indicate widespread water sensitivity of vegetation
- Large decreases in protected areas (up to 33%) expected this century. Currently area is 15 million km^2.
- Ability of these regions to serve as net carbon sinks could be abruptly compromised. Currently sink is 0.5 Pg C.

Drought Response and Prediction Implications



MIT, MBL, UC Davis, and Lehigh Univ.

- Multi-model simulations assess response of mature forest (Blodgett, CA) to synthesized "drought" (precipitation deficit) commensurate with the recent multi-year event over California.
- Droughts of varying duration were tested with accompanying "warm" or "cold" temperatures.
- Net ecosystem productivity shows strong temperature response.
- Model control simulations "different" – but consistency in response.

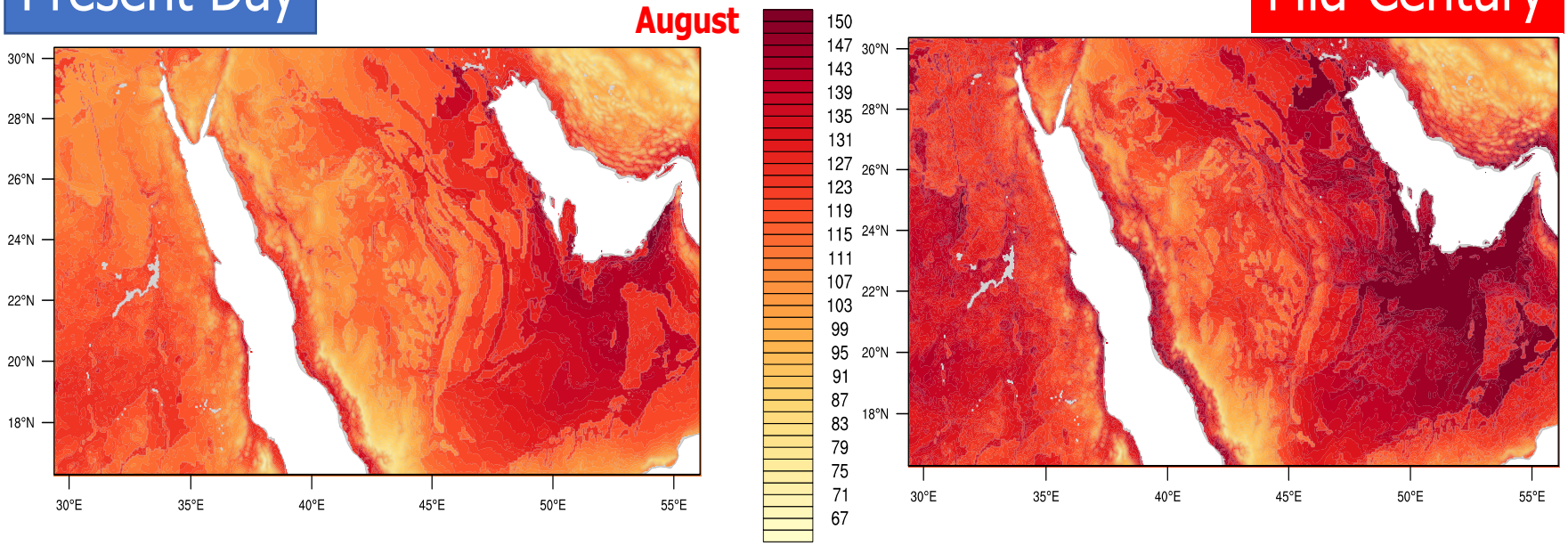
Thresholds in Human Condition and Performance

Maximum NWS Heat Index

Present Day

Mid-Century

August



HEAT INDEX (°F)		
80-91	Very Warm	Fatigue POSSIBLE with prolonged exposure and/or physical activity
90-105	Hot	Sunstroke, heat cramps, or heat exhaustion LIKELY, heat stroke POSSIBLE
105-130	Very Hot	Sunstroke, heat cramps, or heat exhaustion POSSIBLE
130+	Extremely Hot	Heat/Sunstroke HIGHLY LIKELY with continued exposure

Kormucu et al., 2019 (in preparation)

Closing Remarks

General use - reflects an abrupt change in the slope of the relationship between ecosystem performance and environmental condition. Stricter definition - a bifurcation occurs at a critical environmental condition that shifts the ecosystem into an irreversible different state.

Limitations of observations and uncertainty in projections

Careful consideration of terms and definitions would promote evaluation and support well-informed adaptive actions.

<u>To secure avoidance and build resilience:</u>

- Biodiversity across scales
- Genetic and functional plasticity
- Sustain self-replacement
- Uncertainty quantification to support decision making
- Control invasive species
- Apportion areas of assisted regeneration with trees from provenances and climates expected in the future
- Protect isolated species
- Reduce fragmentation
- Ensure national and regional networks of comprehensive protected areas
- Monitor natural disturbances climate, and post-harvest conditions.