**Tipping Points and Feedbacks**

*Tipping Point* – a position in a system where a small, additional increase in an external forcing factor triggers internal processes that drive system change – often rapid and unexpected, sometimes irreversible.

*Feedback* – a process within a system that can either accelerate (positive) or dampen (negative) a change in the system driven by an external forcing factor.

Not all feedback processes have tipping points (some are slow and gradual) and not all tipping points feed back to further system change.
Tipping Elements in the Earth System

*Huber, Lenton, and Schellnhuber, in Richardson et al. 2011*
The Amazon tipping element

Ocean

Amazon forest

Savanna Dry forest

50% 

Climate change: change in ocean/atmos circulation → reduced rainfall; increased drought

Deforestation: conversion to cropland or pasture → reduced evaporation and water recycling

Dieback

Fire
The Amazon tipping element

Deforestation alone: tipping point at ~20-25% clearing of forest and conversion to cropland and pasture.

Climate change alone: 3-4°C temperature increase in the Amazon region.

Deforestation + climate change: Paris 2°C target would reduce allowable deforestation to significantly less than 25%. Paris commitments - ~3°C temperature rise – would reduce allowable deforestation to near zero.

Nobre and de Simone Borma 2009; Lovejoy and Nobre 2018
10 years of C storage lost in 2005 and 2010 droughts.

Another severe drought hit the Amazon in 2015-2016.

Huber et al., in Richardson et al. 2011; Phillips et al. 2009; Lewis et al. 2011; Brienen et al. 2015
The Boreal Forest Tipping Element

Photo: Brian Stocks
The boreal forest tipping element

Spruce bark beetle: Life cycle in 1 season, not 2; Massive population increase

Dieback

Boreal forest

Climate change: strong warming & drying. Direct stress on trees

Fire

CO₂ emissions

Grassland, Bare soil

Forest harvesting: additional stress on forest; loss of resilience

Permafrost zones

CH₄, CO₂ emissions

Exposure, warming
The SE Asian forest feedback

Ocean maintains rainfall regime over region

Borneo Sumatra rainforests

Strong El Nino event

Drying Fire

Exposure

Tropical Peat Bogs

Deforestation: conversion to palm oil or pasture; direct CO₂ emissions to atmosphere

CO₂ emissions to atmosphere
Planetary Boundaries:
Exploring the safe operating space for humanity in the Anthropocene
Land-system change PB:
Amount of forest cover remaining
IPCC “Reasons for Concern”

Adapted from IPCC 2014

The Paris 2°C Target: Can We Meet It?

The total carbon budget from 1870 is about 1,000 Gt C (emitted as CO₂) for a 66% probability of meeting the 2°C target.

Cumulative human emissions (fossil fuels, cement, land use) from 1870 through 2018 were about 585 Gt C, leaving 415 Gt C in the budget.

Accounting for non-CO₂ gases (e.g. CH₄, N₂O) reduces the C budget by 210 Gt C.

The remaining budget is 205 Gt C in total.

At current rates 10 Gt C per year at current rates, the budget would last only two decades.

Sources; IPCC AR5 WGI SPM; GCP 2018
Carbon Cycle Feedbacks

Assumption: 2°C temperature rise; no deforestation; estimates of C loss by 2100

- Amazon dieback could release 25 (15-55) Gt C
- Boreal forest dieback could release 30 (10-40) Gt C
- Permafrost thawing could release 40 Gt C
- Peat fires in Borneo and Sumatra could release more C

Notes:
1. Higher temperature rises (e.g. ~3°C) would lead to much higher losses of carbon
2. Including the effects of human-driven deforestation would also lead to much higher losses of carbon
3. By comparison, current human emissions are ~10 Gt C yr⁻¹

Steffen et al. 2018
Feedbacks from the Amazon, boreal forest-tundra and Borneo/Sumatra regions could release enough carbon to cut the 2°C carbon budget in half – down to ~100 Gt C, or about 10 years of emissions.

Key finance/investment decisions could make the difference between meeting the Paris climate targets or not.
Climate Change 2017

Global Average Temperature Anomaly, 1880-2017

Baseline is 1951-1980

NASA 2018
An Earth System Perspective

Temperature rise:
Beyond the envelope of natural variability!

Human influence

Summerhayes 2015
Implications of accelerating climate change

IPCC temperature projections

Model mean global mean temperature change for high emission scenario RCP8.5

Model mean global mean temperature change for low emission scenario RCP2.6

IPCC 2013
Earth System moves to a new state? Severe challenge to contemporary civilisation. Possible collapse?

Tipping Points?

Committed

IPCC Projections 2100 AD
Tipping Elements in the Earth System

Huber, Lenton, and Schellnhuber, in Richardson et al. 2011

10 years of C storage lost in 2005 and 2010 droughts

50 to 250 Gt C lost by 2100 from thawing permafrost

Huber, Lenton, and Schellnhuber, in Richardson et al. 2011
Tipping Cascades

Source: J. Donges and R. Winkelmann in Steffen et al. 2018
Earth System Trajectories

Steffen et al. 2018
Is ‘Hothouse Earth’ inhabitable?

- Most of the tropics and subtropics will be too hot for human habitation.
- Changing temperature & rainfall patterns will likely make current large agricultural zones unproductive.
- Sea-level rise of 20-40 m ultimately likely, drowning coastal cities, agricultural areas and infrastructure.
- Maximum carrying capacity of ~1 billion humans (today’s population is 7.5 billion)
The ‘Doughnut’: a safe and just space for humanity

An Economy for the 21st Century

• Systems thinking: dynamic complexity
• Equity: distributive by design
• Biosphere: regenerative by design
Conclusions

Boreal forests, SE Asia tropical forests and the Amazon basin are all important tipping elements/feedbacks in the Earth System. Together they could ‘make or break’ the Paris climate agreement.

Halting deforestation of these regions is also critical for avoiding the Earth’s sixth great extinction event.

The finance sector has an absolutely crucial role to play in keeping these ‘Sleeping Giants in the Earth System’ asleep (or putting them back to sleep).

Halting deforestation is the necessary first step in moving from an exploitative to a regenerative global economy.
Johan's slide
Big world on a small planet
Johan Rockström and Matthias Klum