Climate Change, Fire and Forest Resilience

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Dr. KITAJIMA Kaoru has held faculty positions at Kyoto University, Japan (2013-present) and the University of Florida (1997-2013). She received her B.Sc. from the University of Tokyo and her M.Sc and Ph.D. from the University of Illinois. Her research interests encompass the ecology of seedling regeneration of tropical trees, responses of forest trees to climate and other environmental factors, and ecosystem functions of plant and microbial diversity in tropical forests. She is a member of the Science Council of Japan (Chair, Integrative Biology Committee) and has been elected as President of the Ecological Society of Japan (2024-2026).

ABSTRACT

Multiple SDGs hinge upon tropical forests. To ensure sufficient food and nutrition for all, we must achieve nature-positive production landscapes through both sustainable agriculture and natural forest conservation. Forests continue to be central to mitigation and adaptation responses to climate change, as well as to the conservation of biological and cultural diversity. Reports from the Intergovernmental Panel on Climate Change (IPCC), the Scientific Group of the UN Food Systems Summit, and the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) support these key points for sustainability but also conclude huge uncertainty associated with forest conservation[1, 2]. Many factors underpin this uncertainty. Biologically, there is much uncertainty about whether forest trees will continue to respond positively to increases in atmospheric CO_2 concentration and warmer temperature regimes. Even larger uncertainty exists in relation to fire risks.

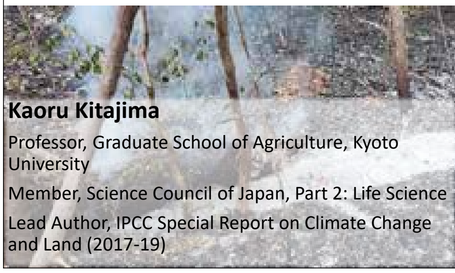
We have a limited understanding of historical fire regimes in many tropical forests, which differ among biogeographical regions, edaphic factors, vegetation characteristics, and the historical interaction of people with forests. Tropical rain forests, which historically never burned, are now burning in Asia and South America due to human-driven fragmentation and degradation of forests and also because of climate-change-related intensification of heat and drought. Historically and currently, tropical forests with extended dry seasons have been lost earlier and more rapidly than rain forests, as drier forests are easy for people to exploit with the use of fire. Because trees are smaller and less dense in drier forests, they have lower carbon sequestration, both in terms of rate and pool size. Yet, tropical dry forests provide multitudes of ecosystem services, including biodiversity conservation, resource basis to support traditional ecological knowledge, soil conservation, and water regulation. The latter two factors are critical at the watershed and regional levels for the sustainability of the production landscape. It is urgent that we understand the adequate ecosystem fire regimes of remaining natural forests, which hinge heavily on the evolutionary ecological characteristics of tree species that dominate each ecosystem. A scientific understanding of forest fire regimes is urgently needed to provide adequate policy advice to local and national governments, not only to sustain critical ecosystem services provided by the forests but also for landscape-level sustainability of food, water, and energy provisioning.

[1] IPCC, 2019: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 896 pp. https://doi.org/10.1017/9781009157988.

[2] Hodson, E., Niggli, U., Kitajima, K., Ral, L., Sadoff, C. Boost nature-positive food production: a paper on Action Track 3. UN Food Systems Summit Scientific Group Report. https://sc-fss2021.org/wp-content/uploads/2021/04/Action_Track_3_paper_Boost_Nature_Positive_Production.pdf

2023.11.17 JIRCAS International Symposium

Climate Change, Fire, and Forest Resilience




http://www.stockholmresilience.org

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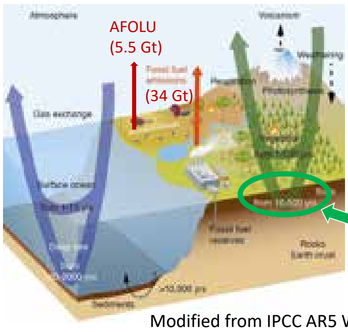
Member, Science Council of Japan, Part 2: Life Science
Lead Author, IPCC Special Report on Climate Change and Land (2017-19)

Forests are particulalry important for conservation of biodiversity and reducing climate change impacts.

WHY?

- **Forests are home to more than 80 per cent of all terrestrial species of animals, plants and insects.**
- **Forests are the most cost-effective way to fight climate change**
  - Forest-based climate change mitigation and adaptation actions, if fully implemented, could reduce greenhouse gas emissions by 15 Gt (gigatons) of CO_2 per year by 2050, which is necessary in order to keep the climate warming within +2°C.
- **The biggest threat to forests is … agriculture** (agriculture, forestry and other land use change, AFOLU)
  → how do we ensure sufficient food and adequate nutrition for all people on the planet while protecting biodiversity and climate?

Conserving natural forests is central to nature-based solutions



Global CO_2 budget
(SRCCL Ch. 2, Table 2.3, 2019)

- CO_2 emission by fossil fuel burning is 34 Gt per year
- Agriculture, forestry and other land use (AFOLU) activities cause net CO_2 emission of ca. 5.5 Gt per year
- Natural forests counter with net CO_2 uptake of 11.7 Gt per year

Modified from IPCC AR5 WG1 Fig.FAQ.6.2.1

Tropical forests, which occupy 45% of all forest areas, conduct 2/3 of the global forest photosynthesis

Global GPP (Gt CO_2 / yr)
40.8
8.3
9.9
(Beer et al. 2010. Science)

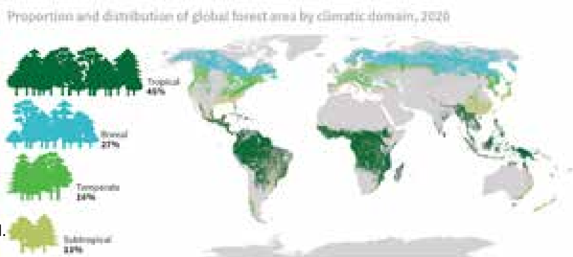
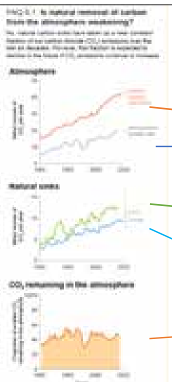


Fig. Source: Global Forest Resources Assessment 2020, FAO



IPCC AR6 WG1 Chapater 5 "Global Carbon and other Biogeochemical Cycles & Feedbacks"

Is natural removal of carbon from the atmosphere weakening?

Anthropogenic carbon emission per year

Amount of CO2 increase in the atmosphere per year

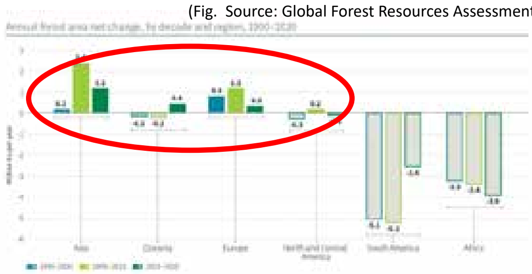
Net amount of CO_2 absorbed by land

Net amount of CO_2 absorbed by sea

Future?

% pf anthropgenic CO_2 emission remaining in the atmosphere

Global FRA 2020: Deforestation continues especially in South America and Africa
(Fig. Source: Global Forest Resources Assessment 2020, FAO)

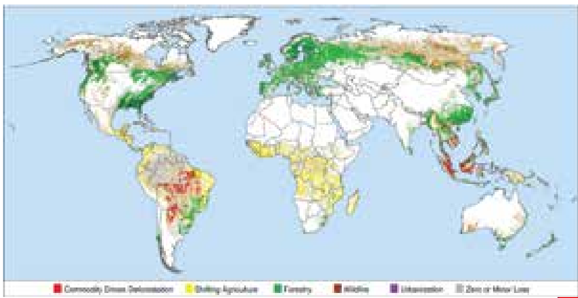


- 240 million of the world poor live in developing countries depend on forests.
- Deforestation accounts for 25% of greenhouse gas emissions.

Even where reforestation and afforeestration are accmulating land carbon stocks, fire can burn up all tha carbon captured in a matter of day or two.

Key drivers of forest cover loss differ among regions

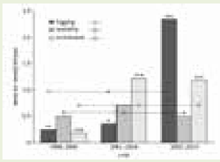
Philip G. Curtis et al. Science 2018;361:1108-1111



Published by AAAS

Fig. 2 Primary drivers of forest cover loss for the period 2001 to 2015.

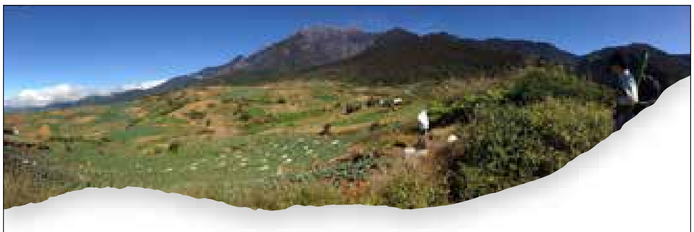
Forest monitoring plots set by FFPRI are lost by illegal logging and conversion to crop fields.



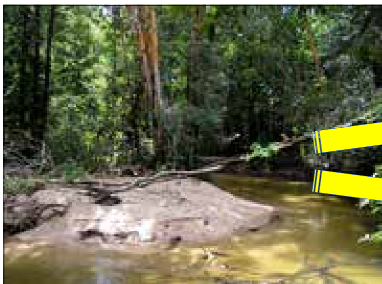
Toyama et al. 2015. Transaction of Royal Society Series B

Logging and land conversion in Kampong Tom, Cambodia
(Photo taken by Kitajima, March 2025)

Eventual fates
→ Several years of growing cassava by small holders
→ Land tenure to the small holders
→ Land purchase by the commercial commodity developers (e.g., for rubber plantations)



Backside of Mt. Kinabalu National Park: unique and biodiverse forests on serpentine soils converted to cabbage fields with fertilizer input → export to megacities in the region



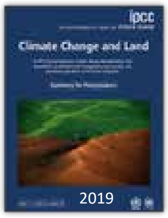
Logging and conversion of swamp forests: logging → loss of soil carbon
（Photo taken by Kaoru Kitajima, 2010, buffer zone forests near Gnung Palung National Park, West Kalimantan ）

Intact peat swamp forests are wet and unlikely to burn, but degradation, fragmentation, water drainage can make them more likely to burn.

Photo source: https://fondationfranklinia.org/en/borneo-peat-swamp-forests/

Fire-driven forest loss has doubled in the last 20 years!

Source：http://WRI.org　(download on 2022.8.17)



Climate change

The Negative Spiral

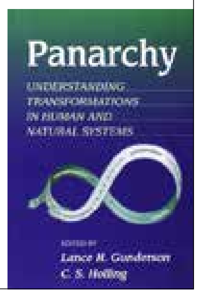
Forest loss &
soil degradation

Agriculture, fragmentation, fire

How can we stop this negative spiral?
How to ensure regional resilience?

Ecological Resilience?

- C. S. "Buzz" Holling (1973) Resilience and stabilityof ecosystems. Annual Review of Ecology and Systematics 4: 1-24
- Holling et al. 2002 in Gunderson & Holling eds. 2002
- **Engineering resilience**: stability near an equilibrium steady state (assumption: single equilibrium state)
- **Ecological resilience**: the magnitude of disturbance that can be absorbed before the system changes its structure to another state (assumption : existence of alternate steady state)



Holling et al. (2002)
Caricature of the four myths of natur

A: Nature flat
B: Nature Balance
C: Nature Anarchic
D: Nature Resilient

1. In Quest of a Theory of Adaptive Change 11

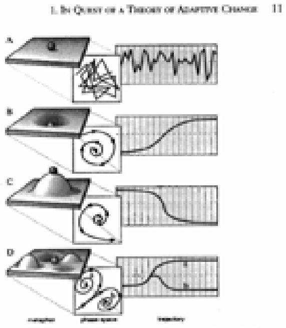
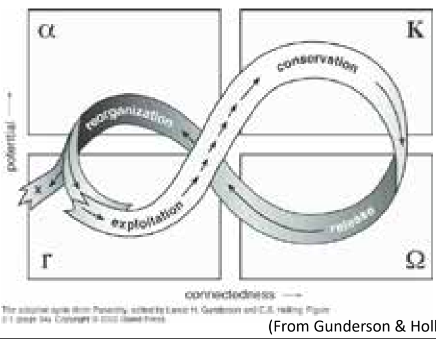


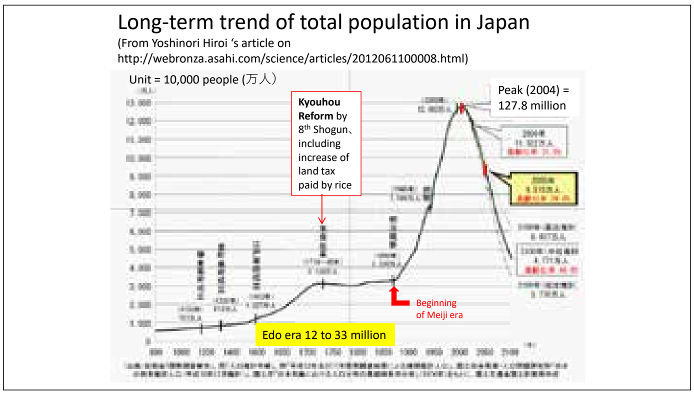
Figure 1-1. Depictions of four myths of nature: (A) Nature Flat, (B) Nature Balanced, (C) Nature Anarchic, and (D) Nature Resilient. Each myth has three representations or metaphors: as stability landscape (left), phase diagram (center), and time-course chart or trajectory of key system variables over time (right).

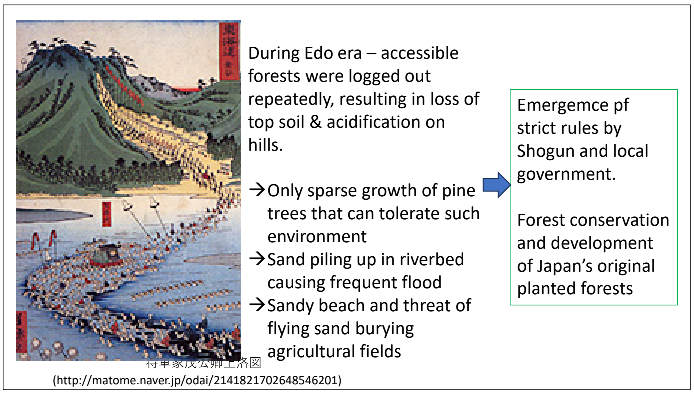
(From Gunderson & Holling eds. 2002)

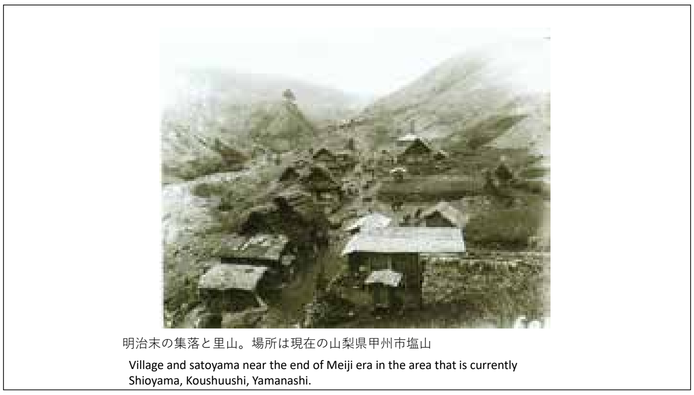
Adaptive cycles in coupled socio-ecological systems

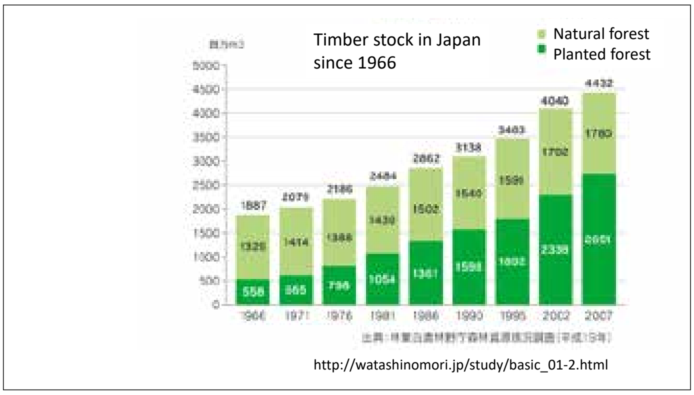


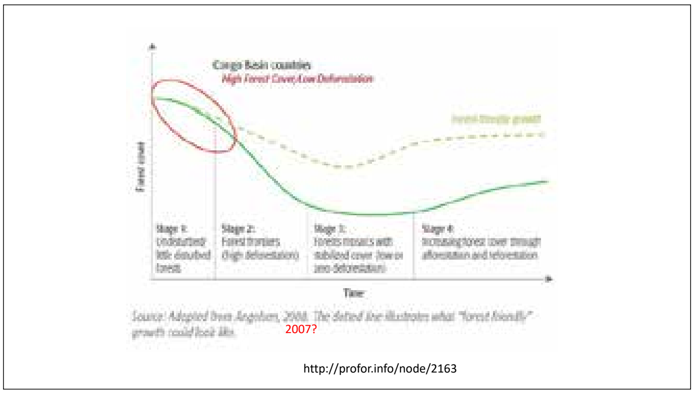
(From Gunderson & Holling eds. 2002)

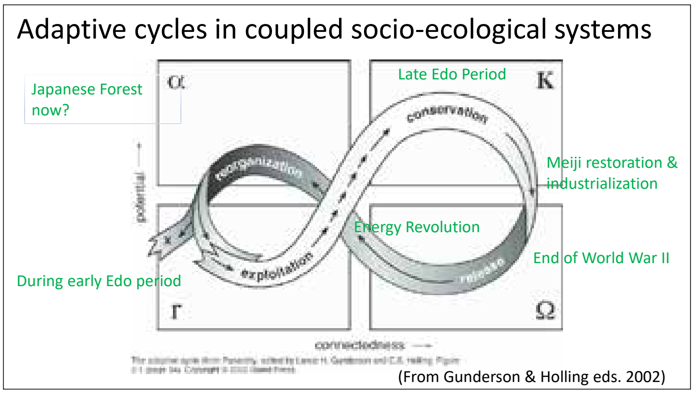

Long-term trend of total population in Japan
(From Yoshinori Hiroi 's article on
http://webronza.asahi.com/science/articles/2012061100008.html)
Unit = 10,000 people (万人)
Kyouhou Reform by 8th Shogun, including increase of land tax paid by rice
Peak (2004) = 127.8 million
Beginning of Meiji era
Edo era 12 to 33 million


During Edo era – accessible forests were logged out repeatedly, resulting in loss of top soil & acidification on hills.
→Only sparse growth of pine trees that can tolerate such environment
→Sand piling up in riverbed causing frequent flood
→Sandy beach and threat of flying sand burying agricultural fields
Emergemce pf strict rules by Shogun and local government.
Forest conservation and development of Japan's original planted forests
将軍家茂公御上洛図
(http://matome.naver.jp/odai/2141821702648546201)


明治末の集落と里山。場所は現在の山梨県甲州市塩山
Village and satoyama near the end of Meiji era in the area that is currently Shioyama, Koushuushi, Yamanashi.


Timber stock in Japan since 1966
Natural forest
Planted forest
1887
2079
2186
2484
2862
3138
3483
4040
4432
http://watashinomori.jp/study/basic_01-2.html


Congo Basin countries
High Forest Cover, Low Deforestation
Forest cover
Stage 1: Undisturbed little disturbed forests
Stage 2: Forest frontiers (high deforestation)
Stage 3: Forests mosaics with stabilized cover (low or zero deforestation)
Stage 4: Increasing forest cover through afforestation and reforestation
Time
Source: Adapted from Angelsen, 2008. The dotted line illustrates what "forest friendly" growth could look like.
2007?
http://profor.info/node/2163


Adaptive cycles in coupled socio-ecological systems
Japanese Forest now?
Late Edo Period
Meiji restoration & industrialization
Energy Revolution
End of World War II
During early Edo period
conservation
reorganization
exploitation
release
potential
connectedness
(From Gunderson & Holling eds. 2002)

Fire regimes = frequency & intensity of fire

FIRE RESILIENT FORESTS

- **Seasonal dry forests** → frequent fire → less accumulation of fuel → dominance of trees that survive fire with thick burk, coexistence with grass and other herbaceous vegetation
- **Ever wet forests** → less frequent fire accumulation of fuel → intense fire → stand replacement of trees with sertoninous cones

FIRE NON-RESILIENT FOREST

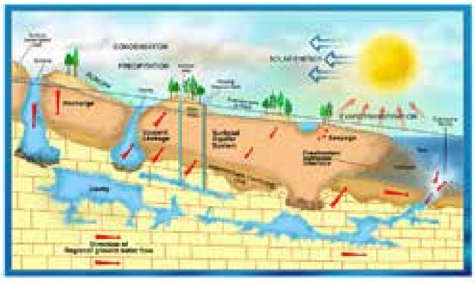
- **Very wet forest** → never burns (no fire-adapted species)

anthropogenic changes (forest isolation, SOIL degradation, drainage, climate-change driven heat & drought) and fire sources (field burning)

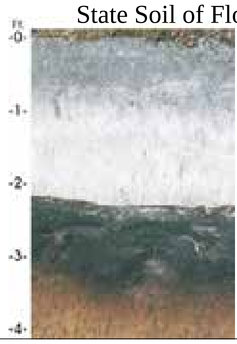
-- > CATASTROPHIC BURN & PERMANENT REGIME SHIFTS?

FIRE REGIMES IN FLORIDA

Background: made of limestone bedrock topped by sand deposits → Florida aquifer with underground river that runs from north to south



Spodosol example: State Soil of Florida: Myakka Series



A horizon: White-grey sand (Some consider it "E" horizon, the zone of strong eluviation)

B horizon: accumulation of clay and organic matter, and iron oxide in some soils.

http://soils.usda.gov
http://www.fao.org

Pine Sandhill dominated by *Pinus palustris* (longleaf pine) in North-Central Florida: ecosystem maintained by frequent low-intensity fire to maintain open understory (historically 92 million acres → now only 2 million acres)

Burn compartments with contrasting land use history and management

Frequent cold-season (winter) burns | **Growing-season (summer) burns**

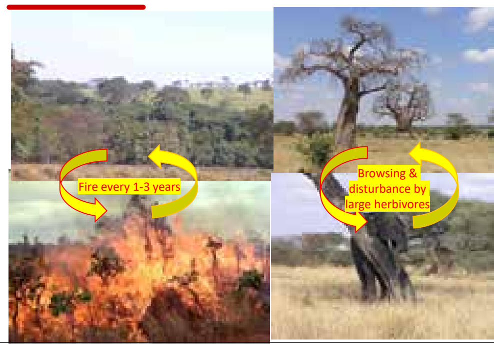
Colonization by evergreen oaks change the fire regimes: oak leaves are difficult to burn, they compete for light to prevent regeneration of pine, but when it burns, the fire becomes too intense.

Degraded pine sandhill | **One year after burn**

Original fire regimes of forests and savannas

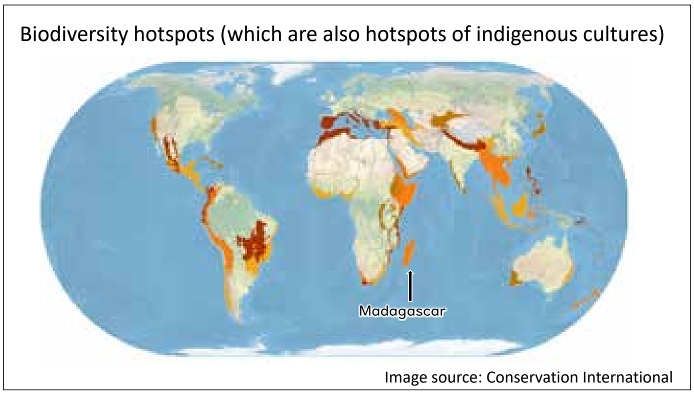
- **Fire dependent forests**: need frequent low intensity fires (every 1-5 years)
- **Fire tolerant forests** with intermediate frequency and intensity of burn (every 5-20 years)
- **Stand-replacement forest**: intense fire with 30-50 intervals result in death of all plants, with the dominant tree species with adapation to dispers seeds to the ashed land (with serotinous cones & fruit that open in response to the heat, etc.)
- **Forest that historically never experienced fire**: e.g., rain forests

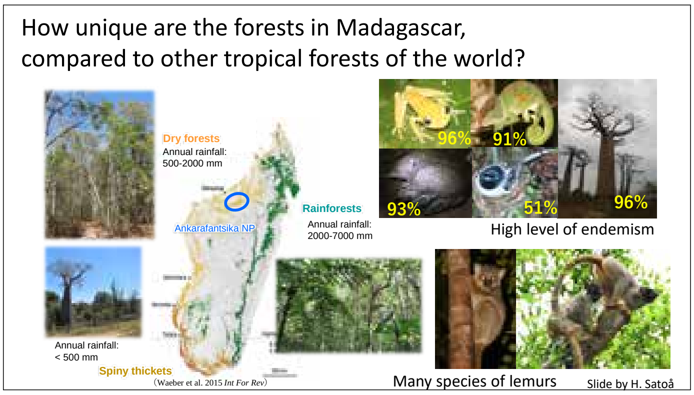
Alternative states in a savanna in Zimbabue

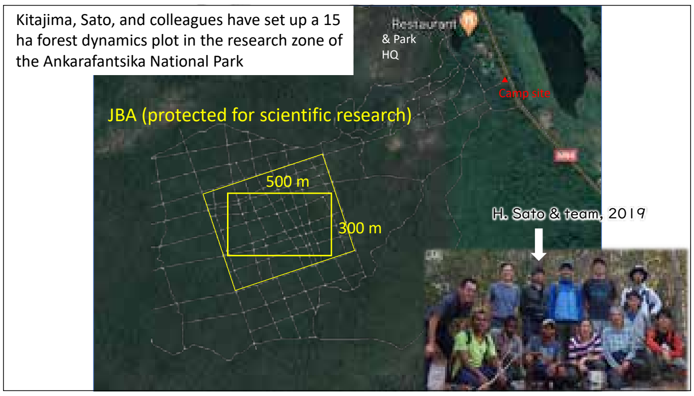


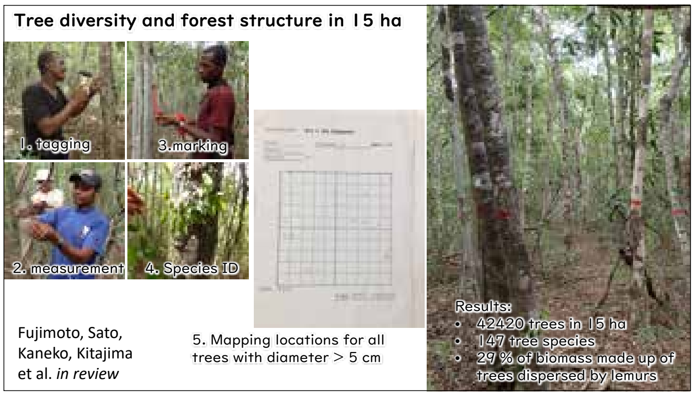

Alternative states in a savanna in Zimbabue
In Miombo-savannah continuum, experimental suppression of fire and access by large herbivores cause shifts to closed forest.

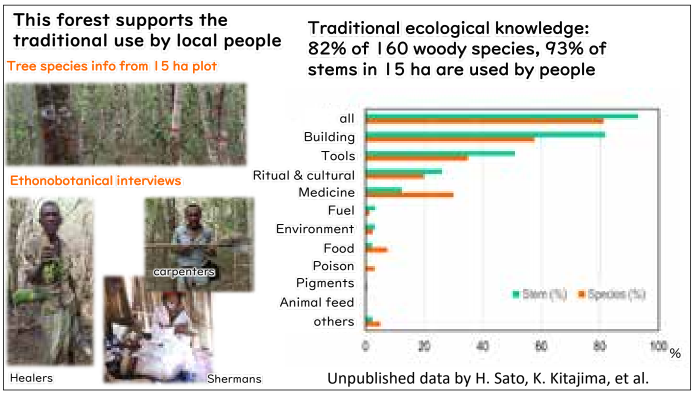

Convesion of tropical forests, in paricular peat swamp forests, to agricultural development result in rapid loss of soil C. [photos taken by K. Kitajima in 2010:
natural peat swam forests in Gnung Palung National Park (above).
When such peat swamp forests are conversted by draining water into canal, it results in rapid loss of soil organic matters (right)]


Biodiversity hotspots (which are also hotspots of indigenous cultures)
Madagascar
Image source: Conservation International

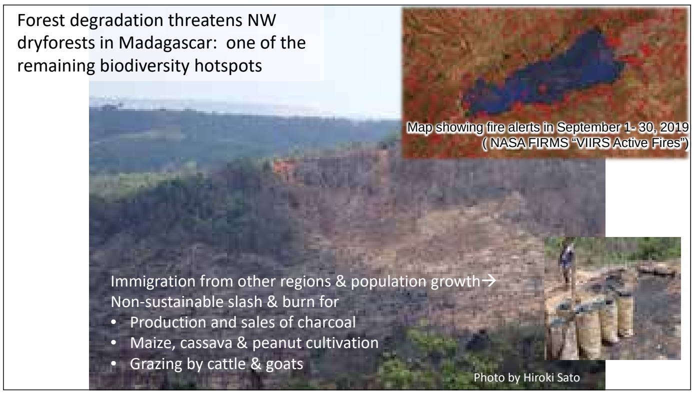

How unique are the forests in Madagascar,
compared to other tropical forests of the world?
Dry forests
Annual rainfall:
500-2000 mm
Ankarafantsika NP
Rainforests
Annual rainfall:
2000-7000 mm
Annual rainfall:
< 500 mm
Spiny thickets
(Waeber et al. 2015 Int For Rev)
96%
91%
93%
51%
96%
High level of endemism
Many species of lemurs
Slide by H. Satoå


Kitajima, Sato, and colleagues have set up a 15 ha forest dynamics plot in the research zone of the Ankarafantsika National Park
Restaurant
& Park
HQ
JBA (protected for scientific research)
500 m
300 m
H. Sato & team, 2019

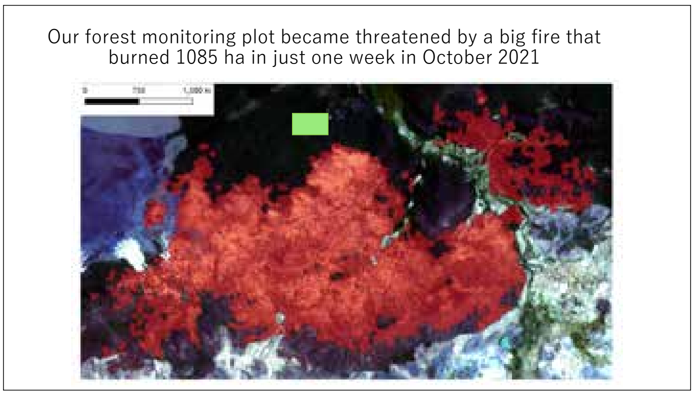

Tree diversity and forest structure in 15 ha
1. tagging
3.marking
2. measurement
4. Species ID
Fujimoto, Sato, Kaneko, Kitajima et al. in review
5. Mapping locations for all trees with diameter > 5 cm
Results:
42420 trees in 15 ha
147 tree species
29 % of biomass made up of trees dispersed by lemurs


This forest supports the traditional use by local people
Tree species info from 15 ha plot
Ethonobotanical interviews
carpenters
Healers
Shermans
Traditional ecological knowledge: 82% of 160 woody species, 93% of stems in 15 ha are used by people
all
Building
Tools
Ritual & cultural
Medicine
Fuel
Environment
Food
Poison
Pigments
Animal feed
others
Stem (%)
Species (%)
0
20
40
60
80
100
%
Unpublished data by H. Sato, K. Kitajima, et al.


Need to consider landscape-level conservation
Forests on the hills: support TEK, prevent soil erosion & regulate water supply
Valleys for rice production, cattle grazing, fruit trees, fish, etc.
Since 1927, Ankarafantsika National Park has promoted coexistence of biodiversity with indigenous people


Forest degradation threatens NW dryforests in Madagascar: one of the remaining biodiversity hotspots
Map showing fire alerts in September 1- 30, 2019
("NASA FIRMS "VIIRS Active Fires")
Immigration from other regions & population growth→
Non-sustainable slash & burn for
• Production and sales of charcoal
• Maize, cassava & peanut cultivation
• Grazing by cattle & goats
Photo by Hiroki Sato

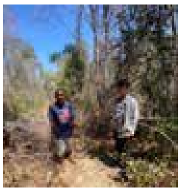

Remaining forests in the Ankarafantsika National Park supply clean water to Marovay, the second largest rice producing region in Madagascar.
(Jacquline et al. 2010, World Bank 2015)
Marovoay
Google Earth
Slide courtesy of Hiroki Sato


Our forest monitoring plot became threatened by a big fire that burned 1085 ha in just one week in October 2021

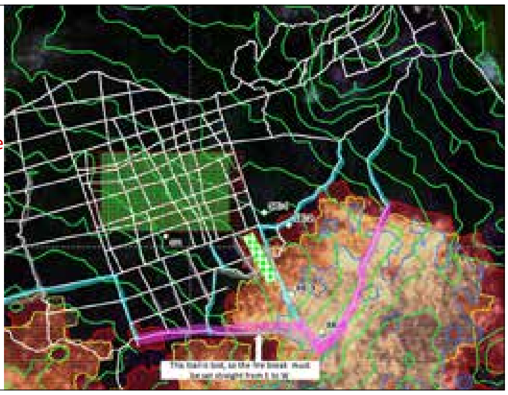

The first fire: some trees are alive, but lots of dead wood
burned
trail
unburned
Once burned, it is prone to burn again
After repeated fire, rapid desertification & soil erosion
Photos by Hiroki Sato

Epilogue:
What I was doing over two weeks last month (Sept, 2023)

Planning fire break line with local assistants



Alfa and Rova

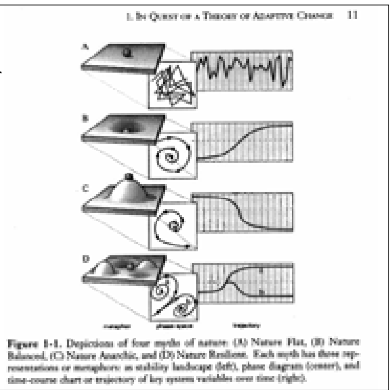


Drone view of the completed fire break three weeks later
(Rova with 5 local villagers x 5 days/ week x 3 weeks)

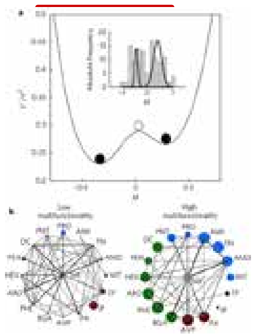
Holling et al. (2002)
Caricature of the four myths of natur

A: Nature flat
B: Nature Balance
C: Nature Anarchic
D: Nature Resilient

(From Gunderson & Holling eds. 2002)



Alternative states of dry lands in the world



Key messages

- Globally, tropical forests are key for mitigation of climate change and carbon neutral
- Importance of proper understanding of fire regimes in many tropical forests, especially those in seasonally dry forests
- Under climate change, fire risk is increasing, especially in combination with forest fragmentation
- Shifts in fire regimes threatens biodiversity conservation and othger ecosystem services provided by the forest
- **Scientific understanding of fire regimes is a critical part of sustainable management of production landscapes**