Transforming landscapes with fire: rapid deforestation following early human settlement in New Zealand

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NATIONAL GEOGRAPHIC

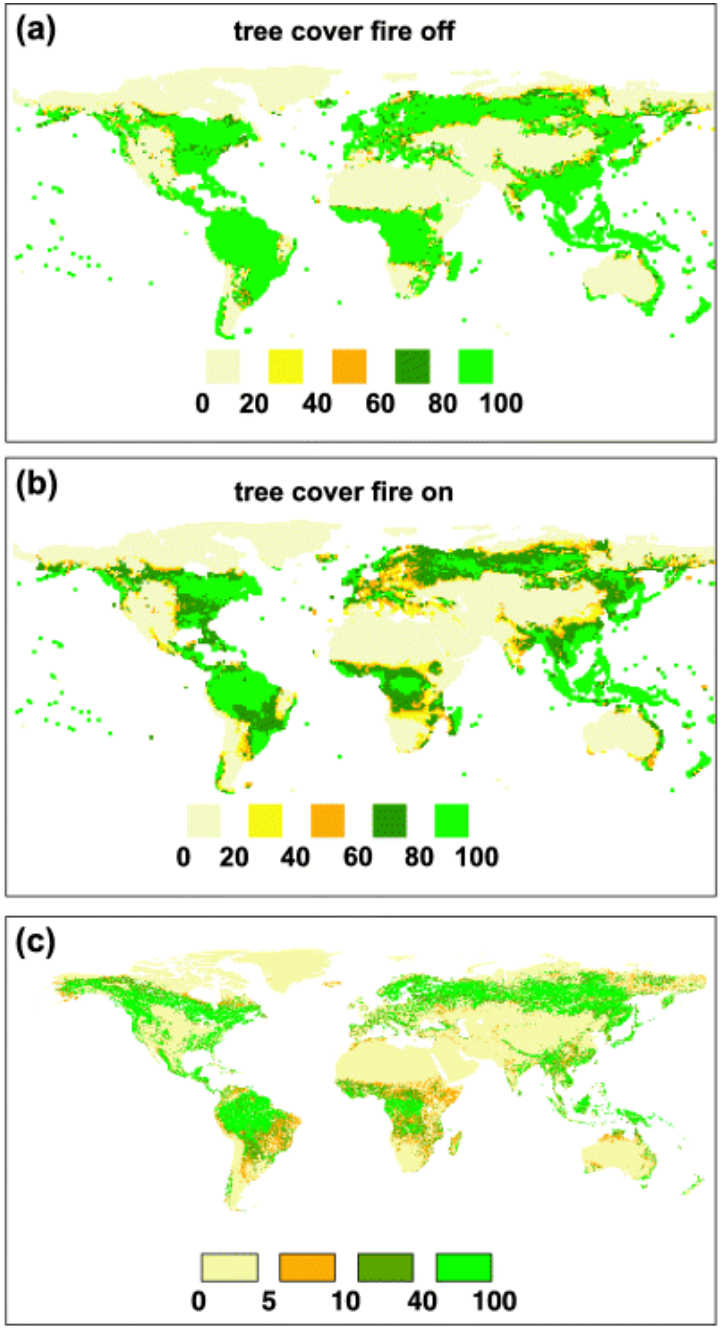
Outline

1. Background on primary questions
2. The New Zealand example
3. Implications and ongoing work

Research questions:

1. How does fire shape the global distribution of vegetation?
2. What are the primary controls on fire?
3. What environments are most sensitive to human-set fires?

How does fire shape the global distribution of vegetation?

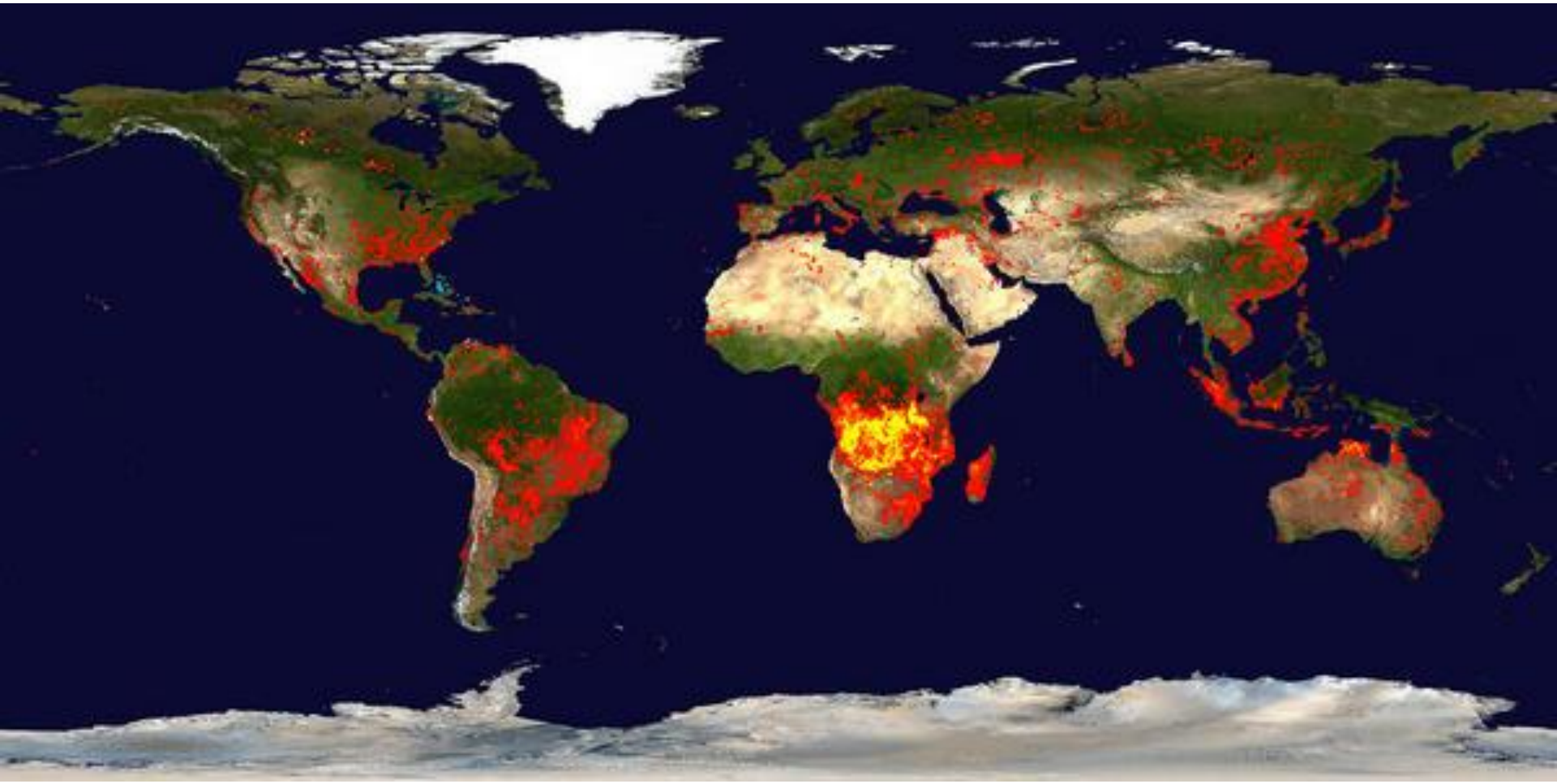


A world without Fire

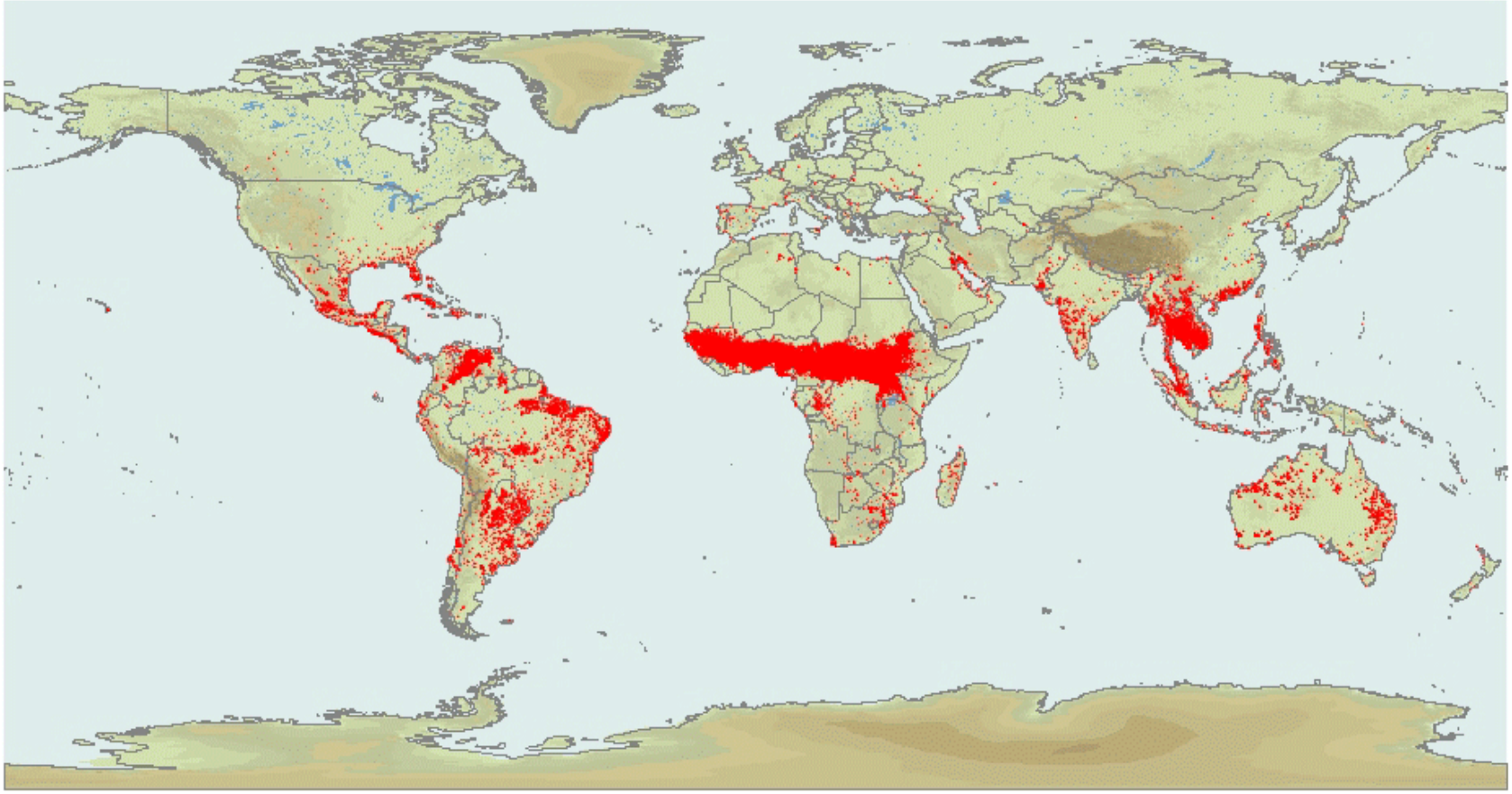
- Closed-canopy forests doubled from 27% to 56%
- 52% C4 grasslands converted to angiosperm-dominated forests
- 41% C3 grassland that were replaced by forests

Bond et al. 2005

MODIS Rapid Response System Global Fire Map July, 2011



MODIS Rapid Response Fire Detections for 2005



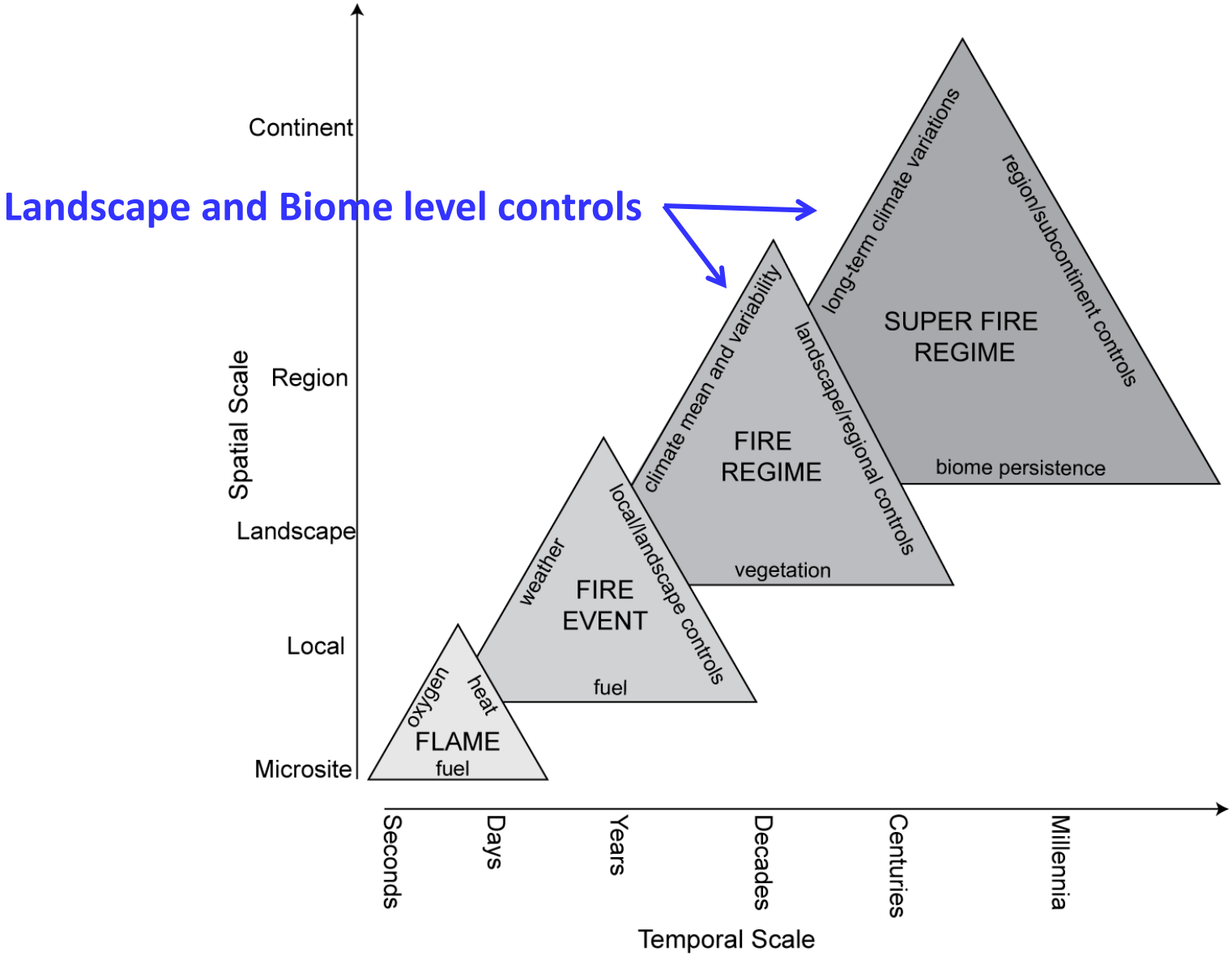
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

- MODIS Active Fire Detections
- World Countries

Active fires are detected using MODIS data from the Terra satellite.
Source: MODIS Rapid Response http://rapidfire.sci.gsfc.nasa.gov
Web Fire Mapper http://maps.geog.umd.edu

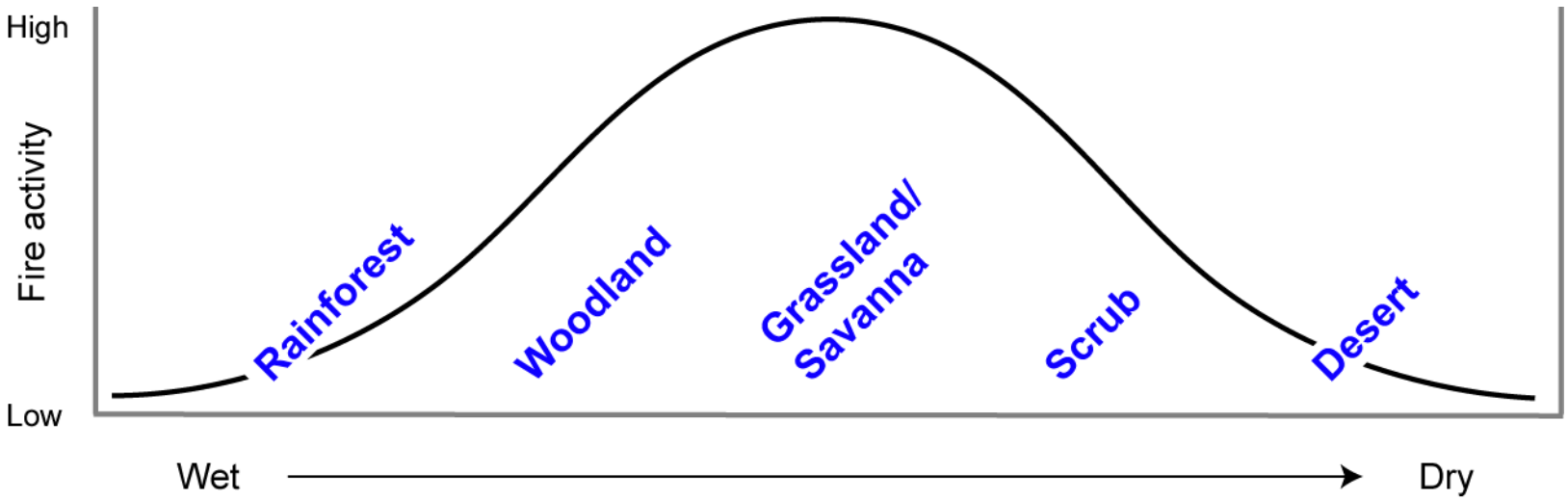
Natural controls on fire

Natural controls on fire

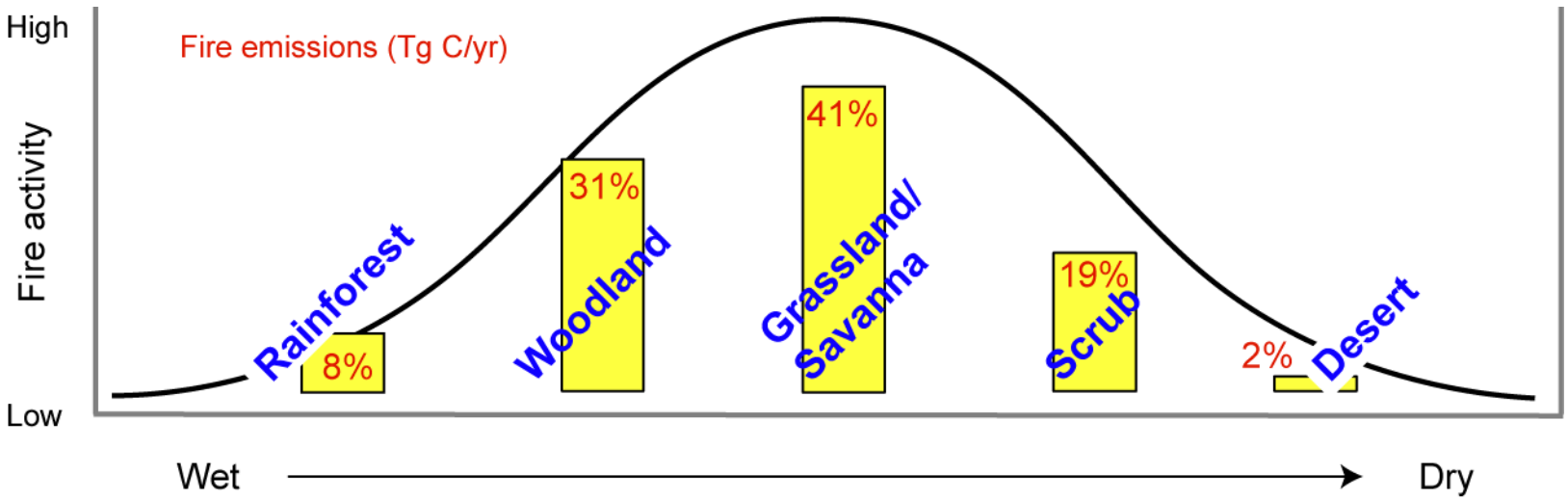


Whitlock et al. 2010

Natural controls on fire

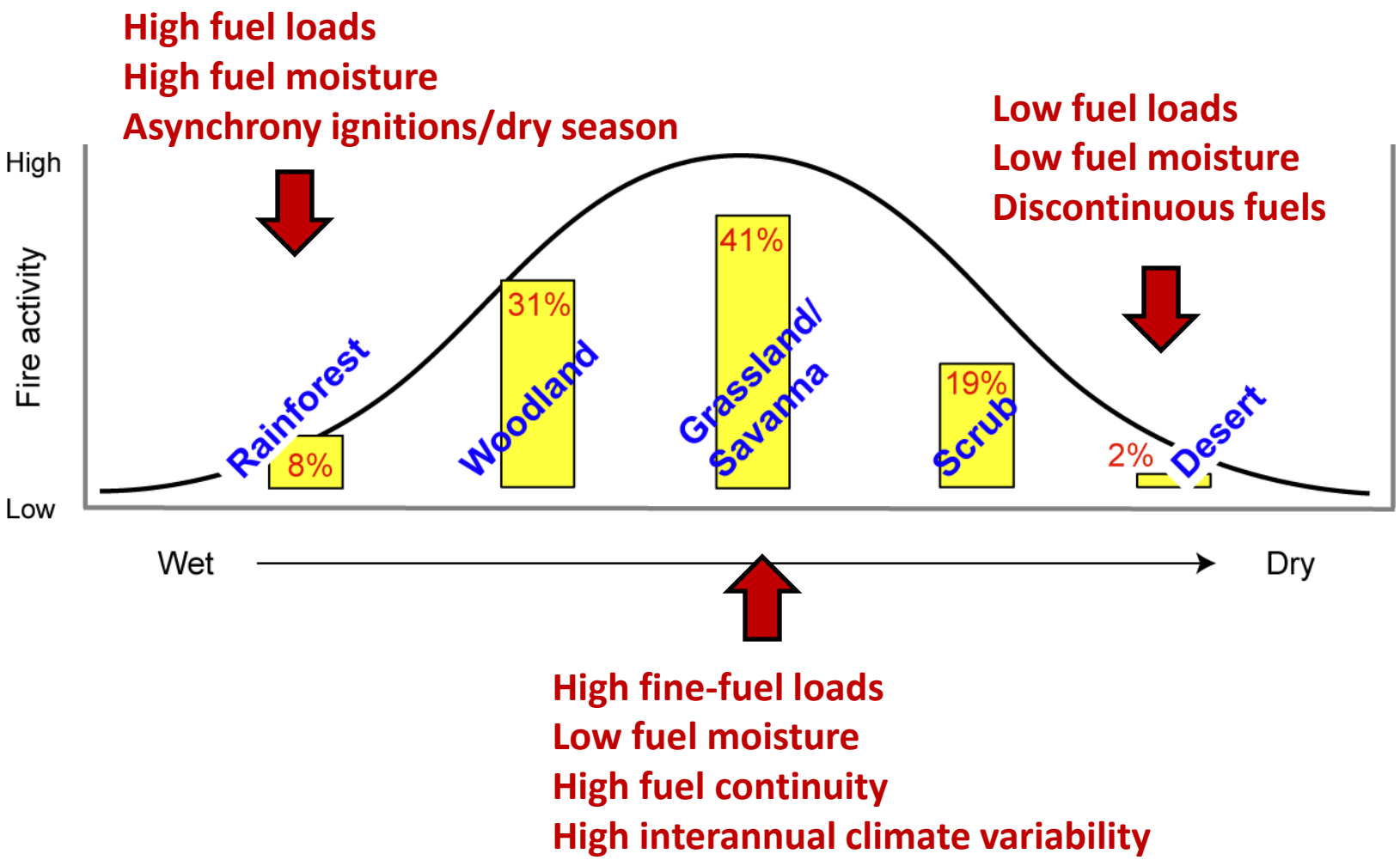


Natural controls on fire



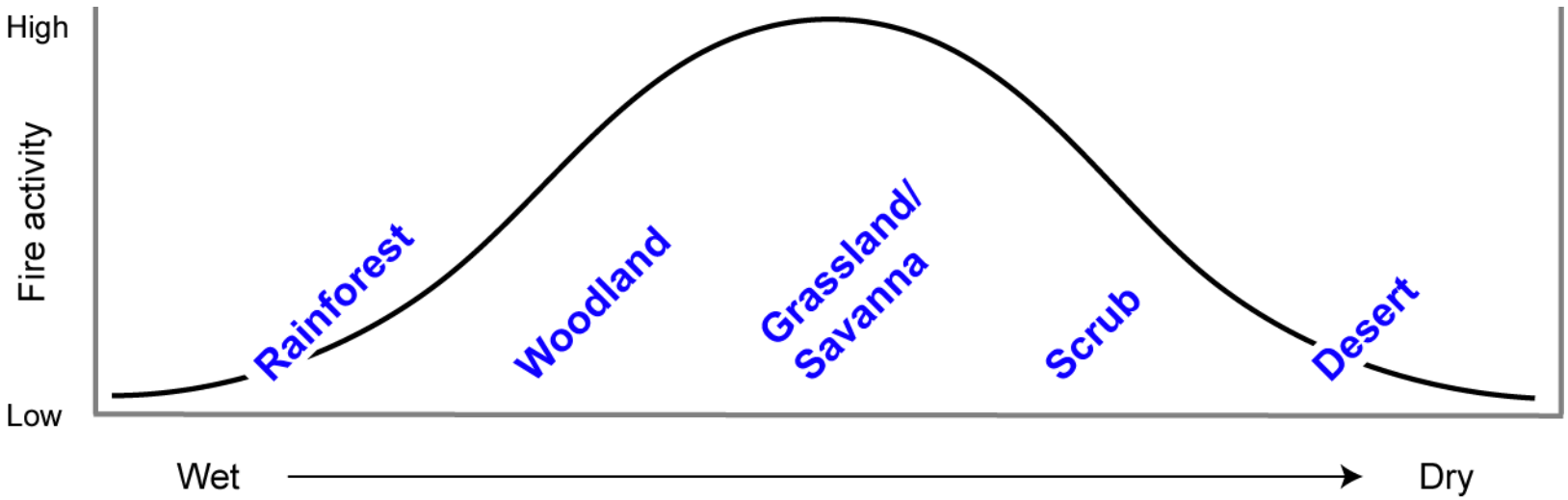
Randerson et al. 2005

Natural controls on fire



Randerson et al. 2005

Natural controls on fire

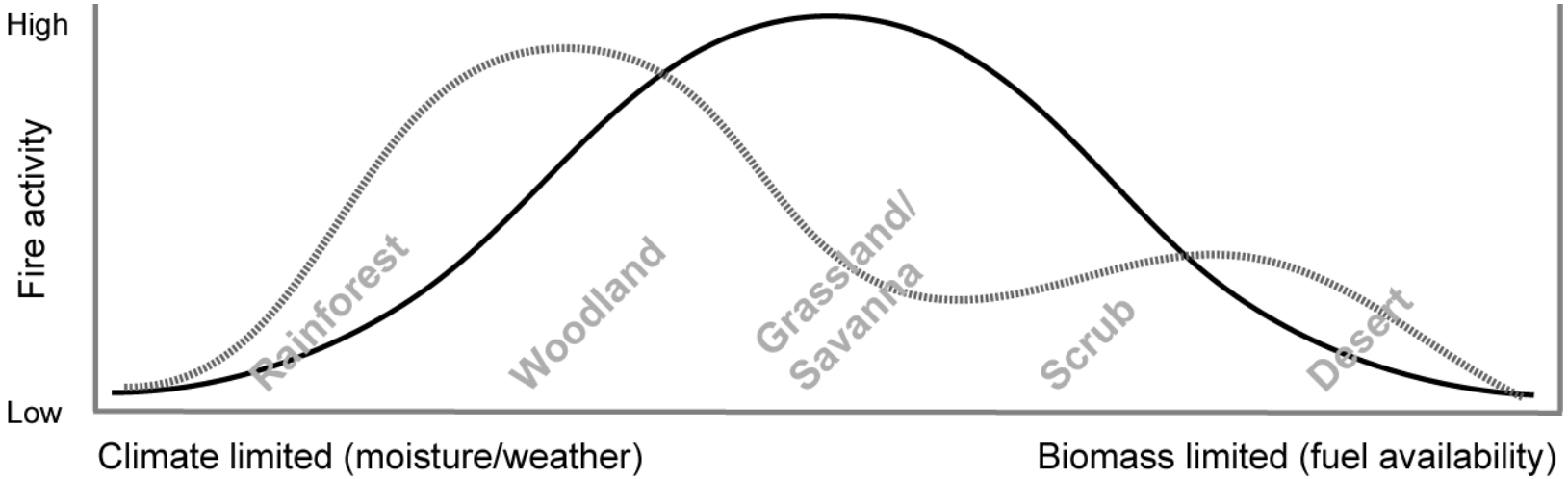


Climate limited (moisture/weather)

Biomass limited (Fuel availability)

Whitaker 1975, Bond et al. 2005, Bond and Keeley 2005, Krawchuck et al. 2011, Krawchuck et al. 2009

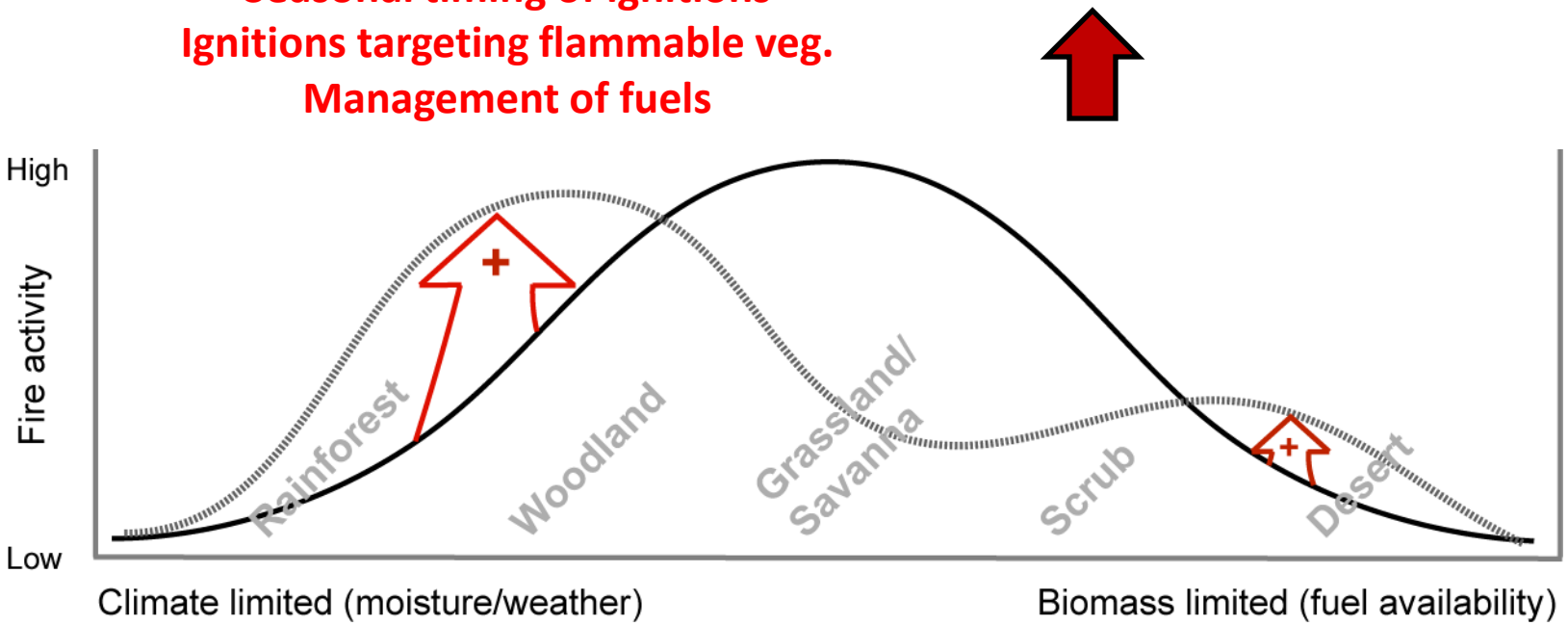
Human influence



Whitlock et al. 2010, Krawchuck et al. 2011, Krawchuck et al. 2009

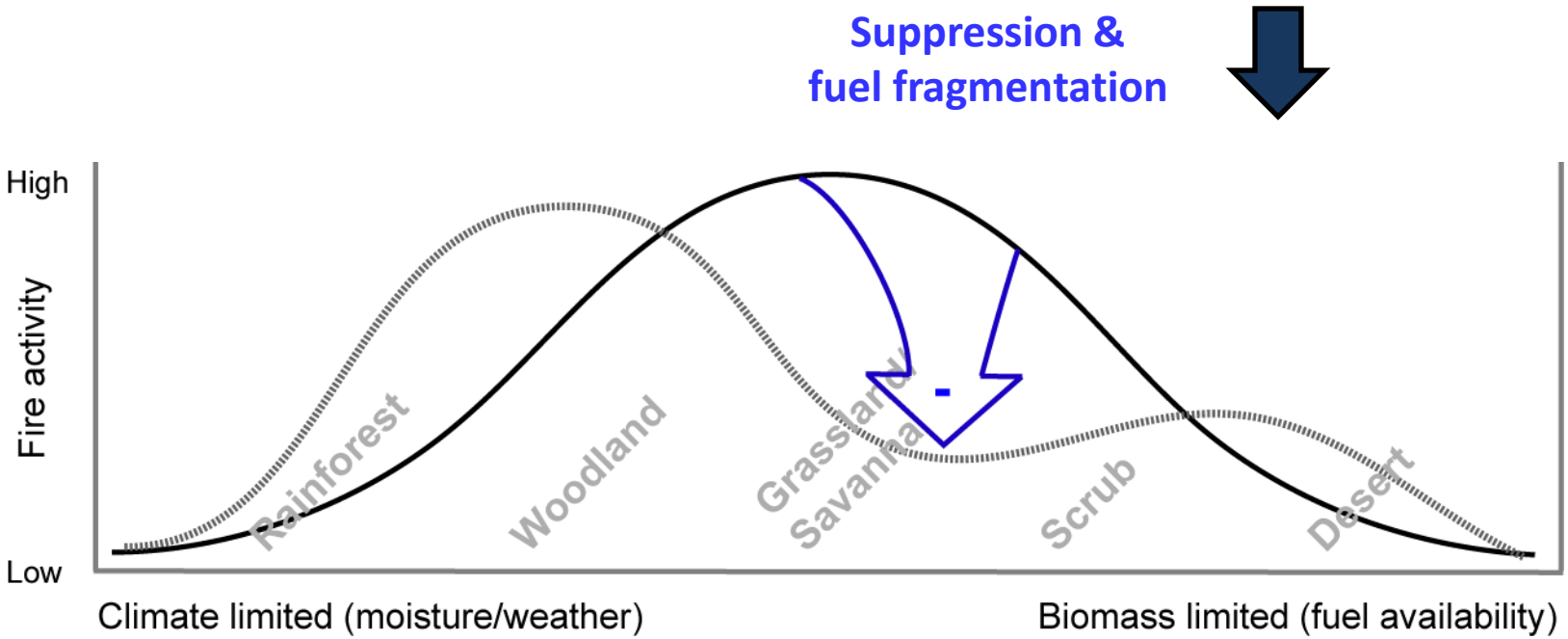
Human influence

Seasonal timing of ignitions
Ignitions targeting flammable veg.
Management of fuels



Whitlock et al. 2010, Krawchuck et al. 2011, Krawchuck et al. 2009

Human influence



Whitlock et al. 2010, Krawchuck et al. 2011, Krawchuck et al. 2009

How do we reconstruct past fires?

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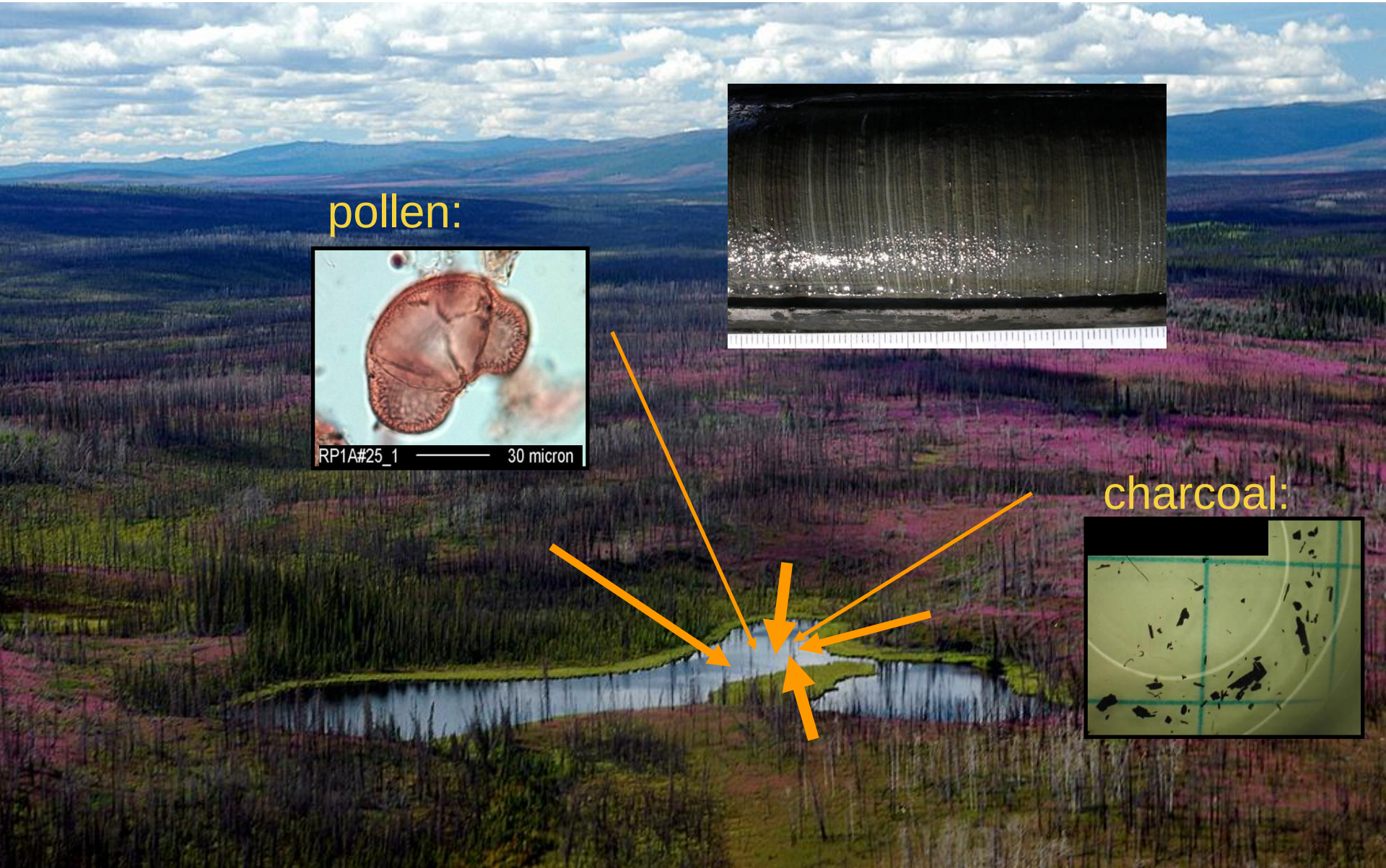
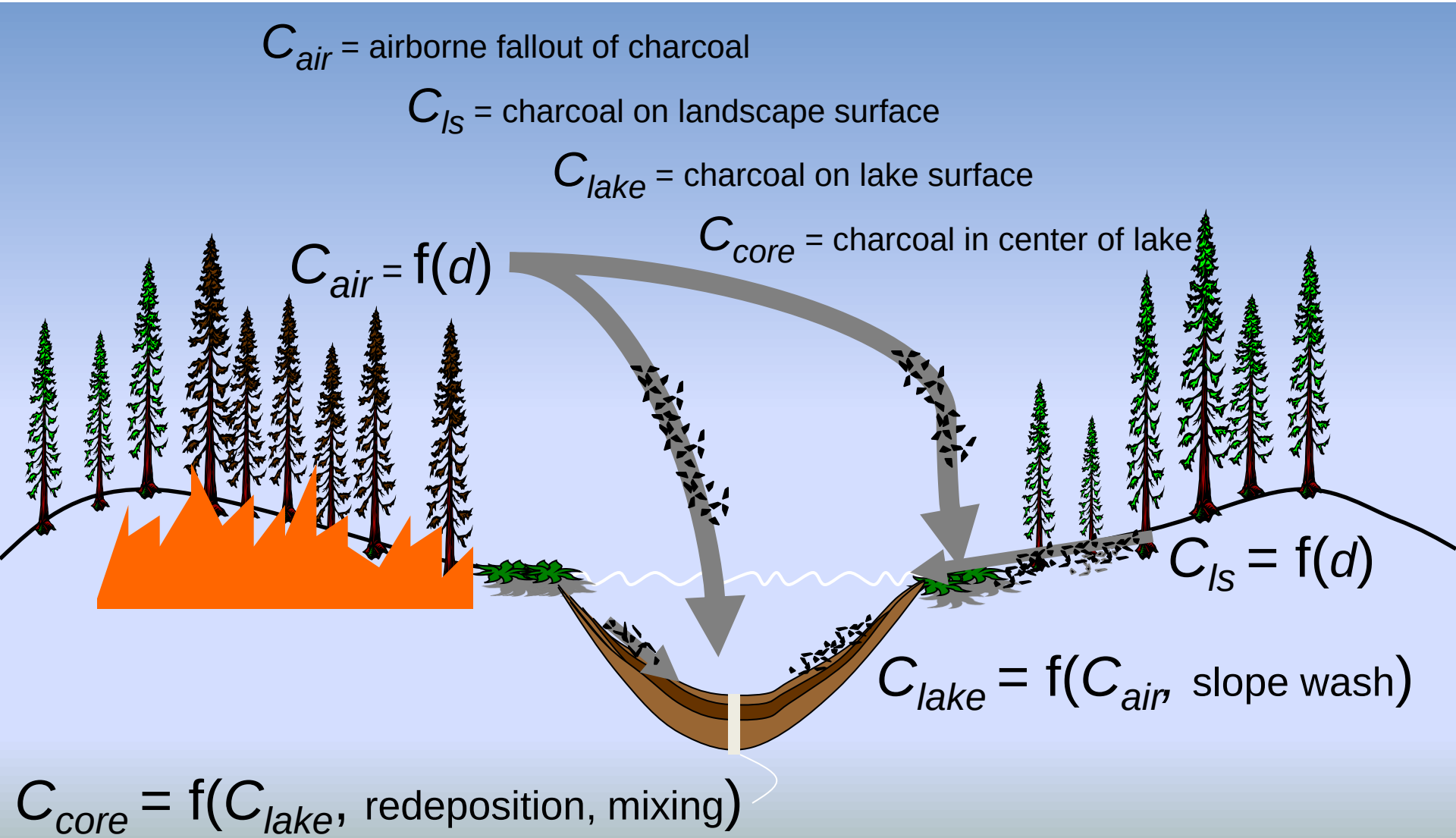


How do we reconstruct past fires?



Higuera et al., 2007, Quaternary Science Reviews.

Coring equipment

Daley Lake 2009

Primary research questions:

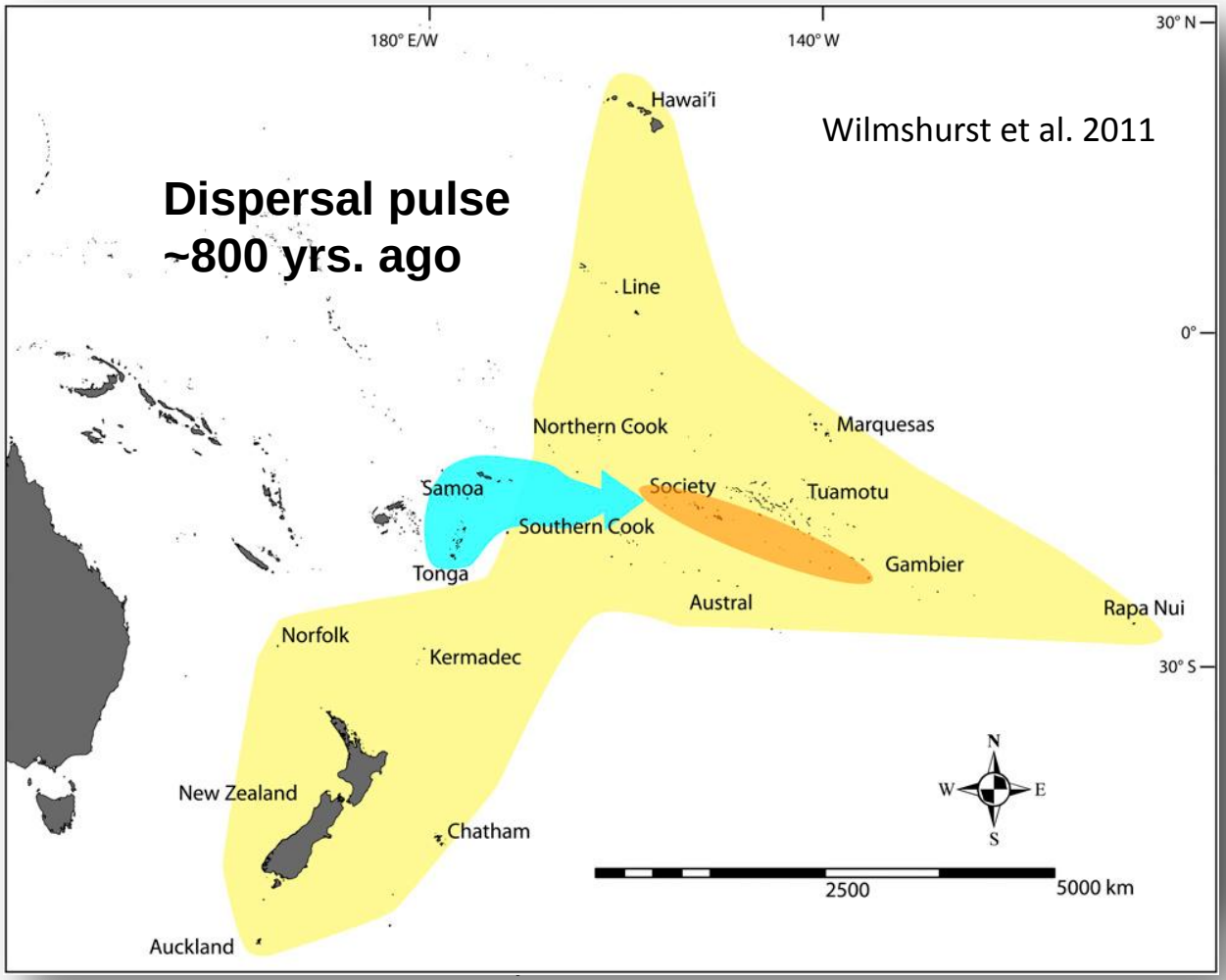
- How does fire shape the global distribution of vegetation?
- What are the primary controls on fire?
- **How sensitive are different settings to human-set fires?**

Humans and fire in New Zealand

Polynesian migration

- Earliest archeological evidence 1280 AD
- Earliest Pacific rat (*Rattus exulans*) evidence 1280 AD
- ~ 100-200 individuals during arrival
- Estimated ~ 1,000 individuals 100 yrs later

Wilmshurst et al. 2008



Native Vegetation

- Pre-Maori 85-90% forested
  - Low elevations, podocarp
  - Higher elevations, beech
- Fires generally rare, ignition limited, return interval ~ 1-2 millennia (Ogden et al. 1998)
- Most tree species poorly adapted to survive fire

Landscape transformation

Prehistoric vegetation

ca. AD 1840 vegetation

Ogden et al. 1998, McGlone and Wilmshurst 1999

Landscape Transformation:

Native Forest → **Bracken/Shrubland** → **European Pasture**

Pre-Maori < AD 1280

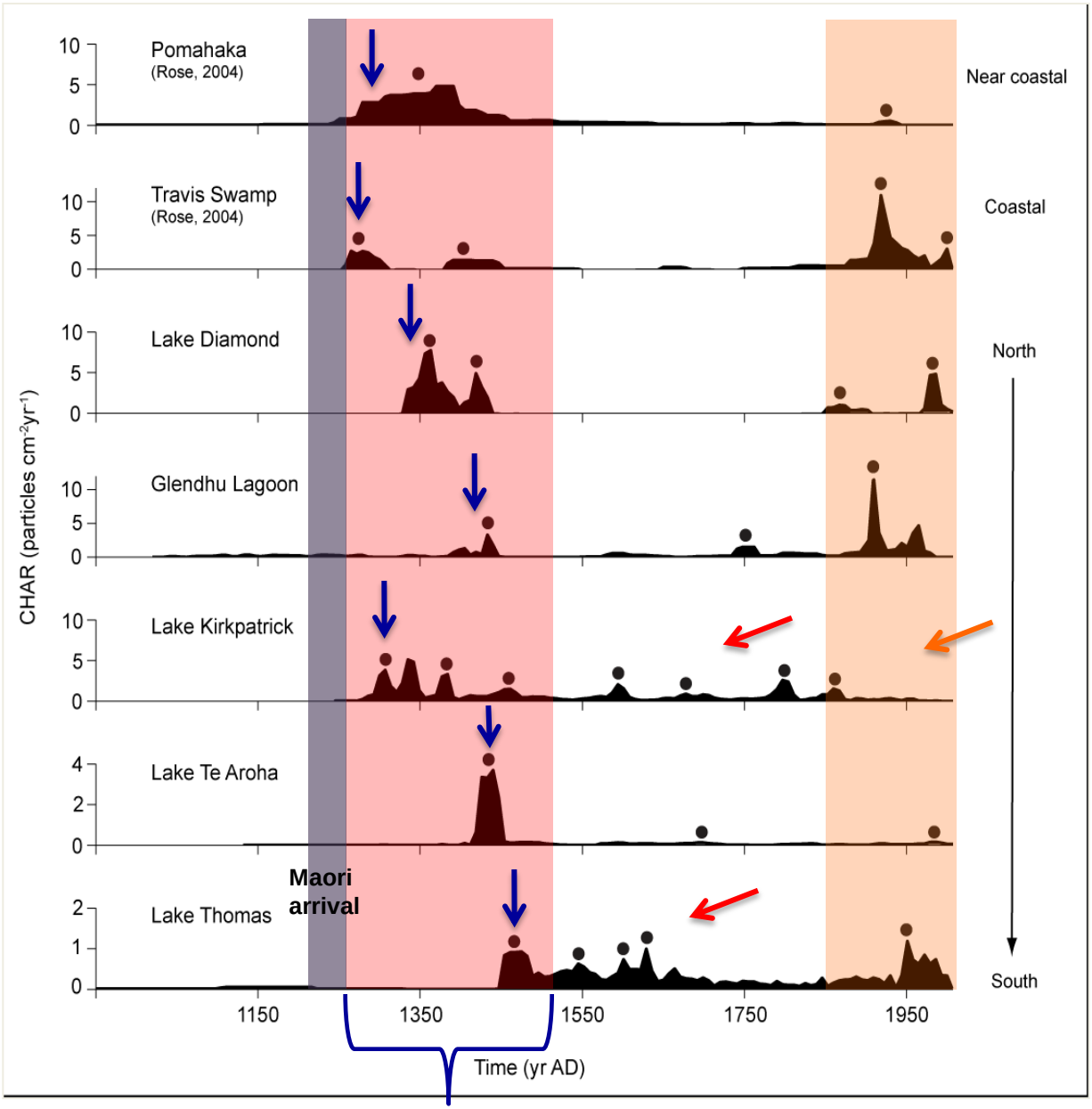
AD 1280-1840

~ AD 1840-present

Hypotheses:

1. Human-set fires were the primary cause of deforestation
2. Variability in patterns of fire are related to biophysical and environmental gradients
3. Human-set fires initiated feedbacks that created fire-prone landscapes

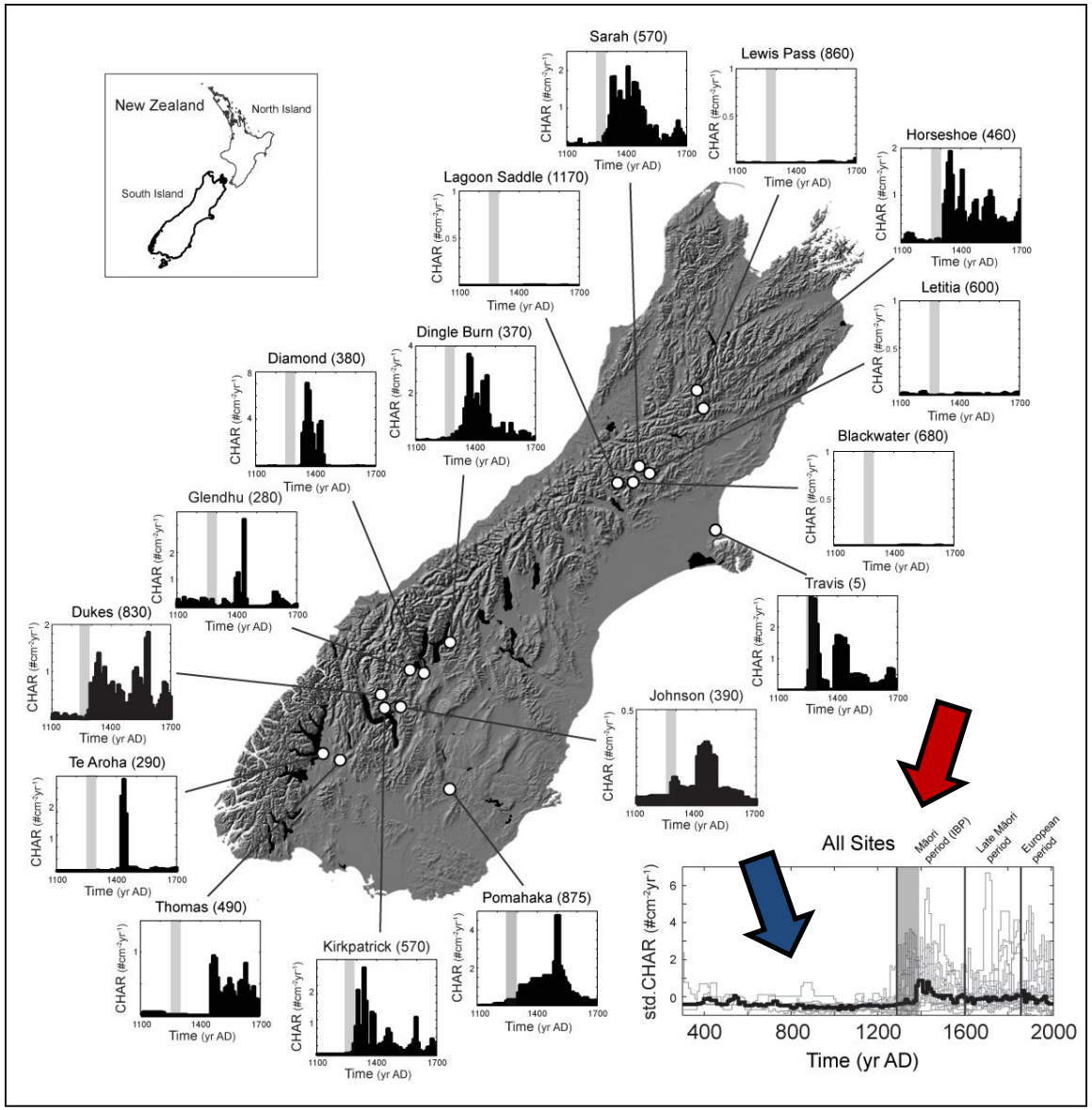
Synchronous fires during the Initial Burning Period - 1300-1500 AD



● = Charcoal peaks- local fire episodes

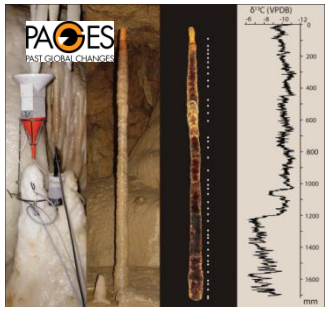
McWethy et al. 2009 The Holocene

South Island, New Zealand

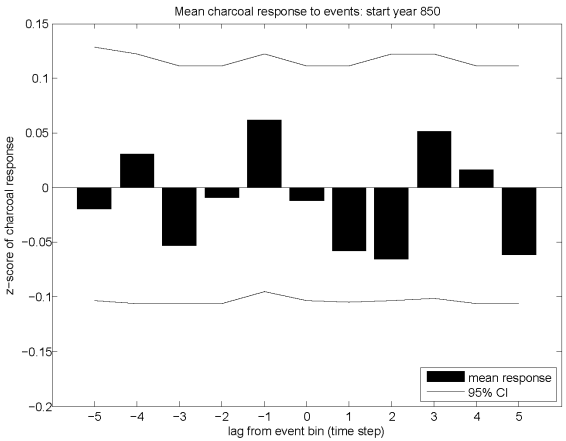


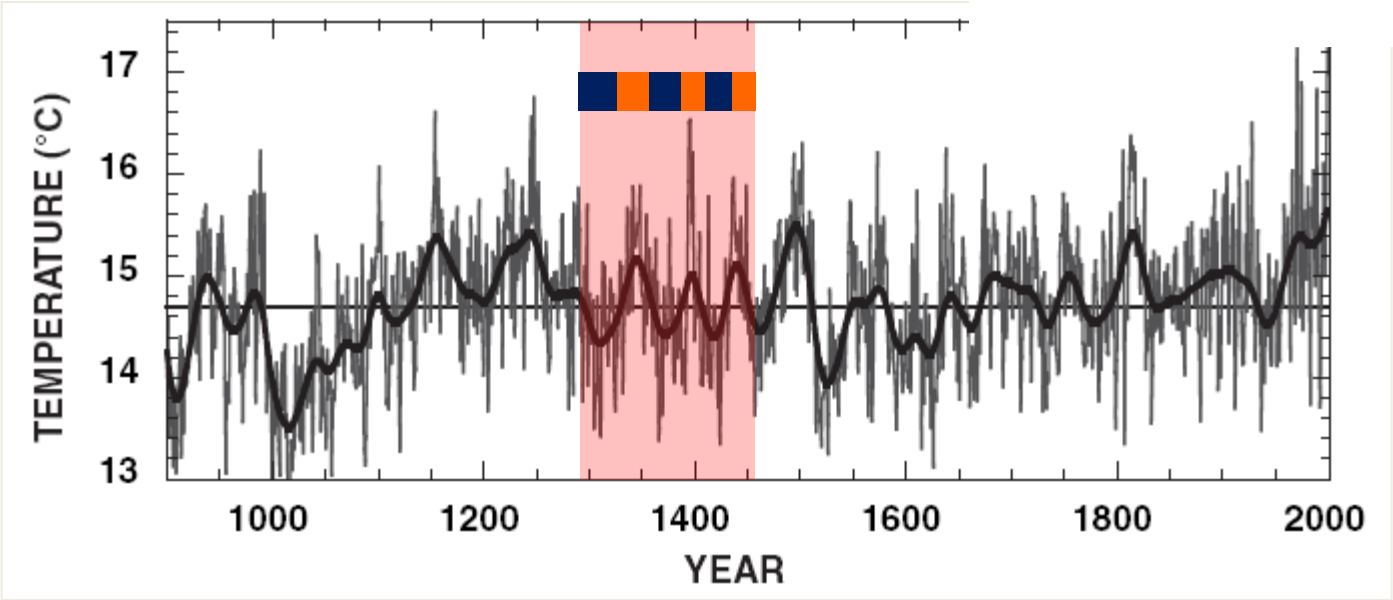
McWethy et al. 2010 PNAS

Multi-proxy Climate Record



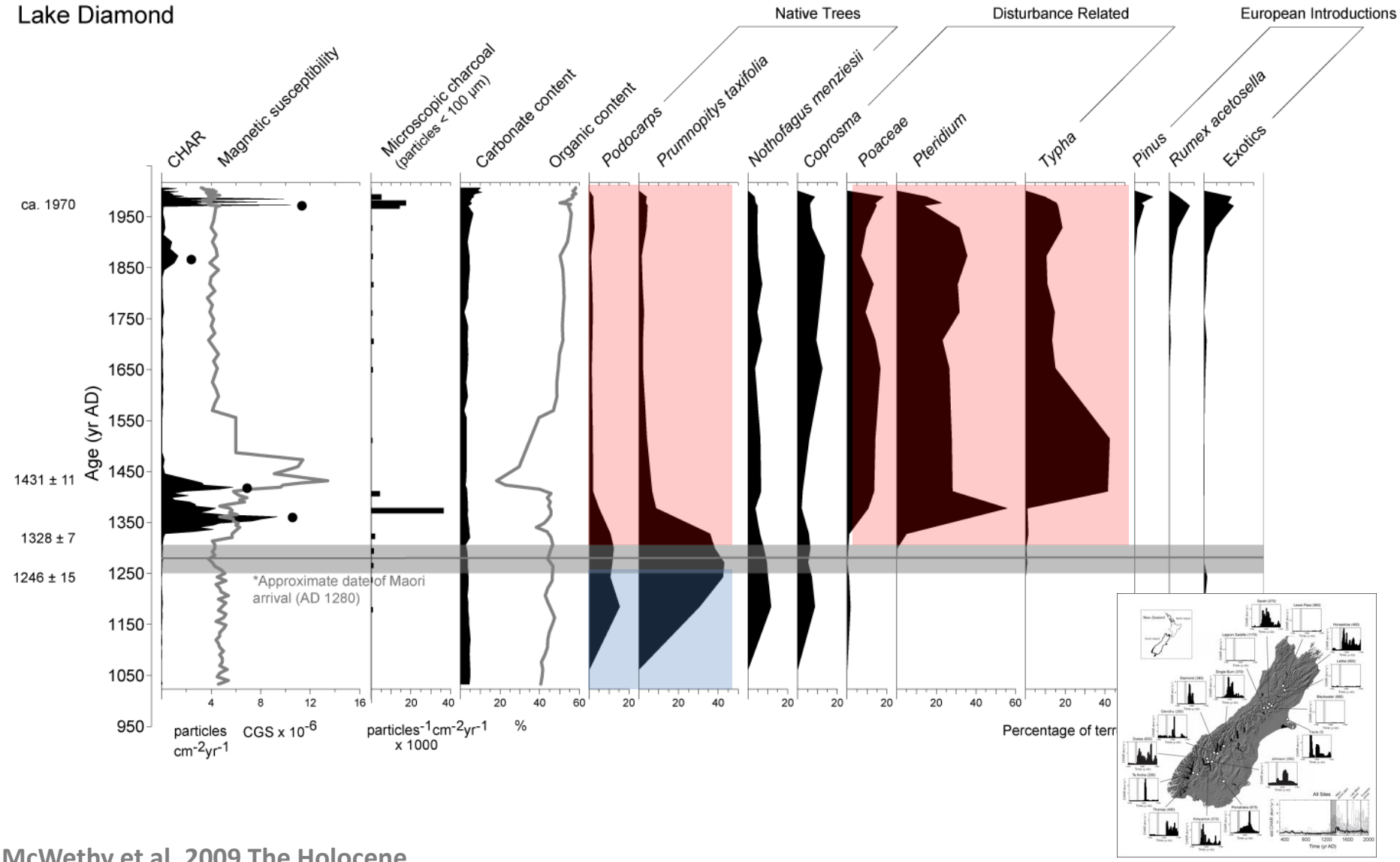
- Tree ring records
- Speleothem stable isotope rec
- Palynology
- Lake sediment





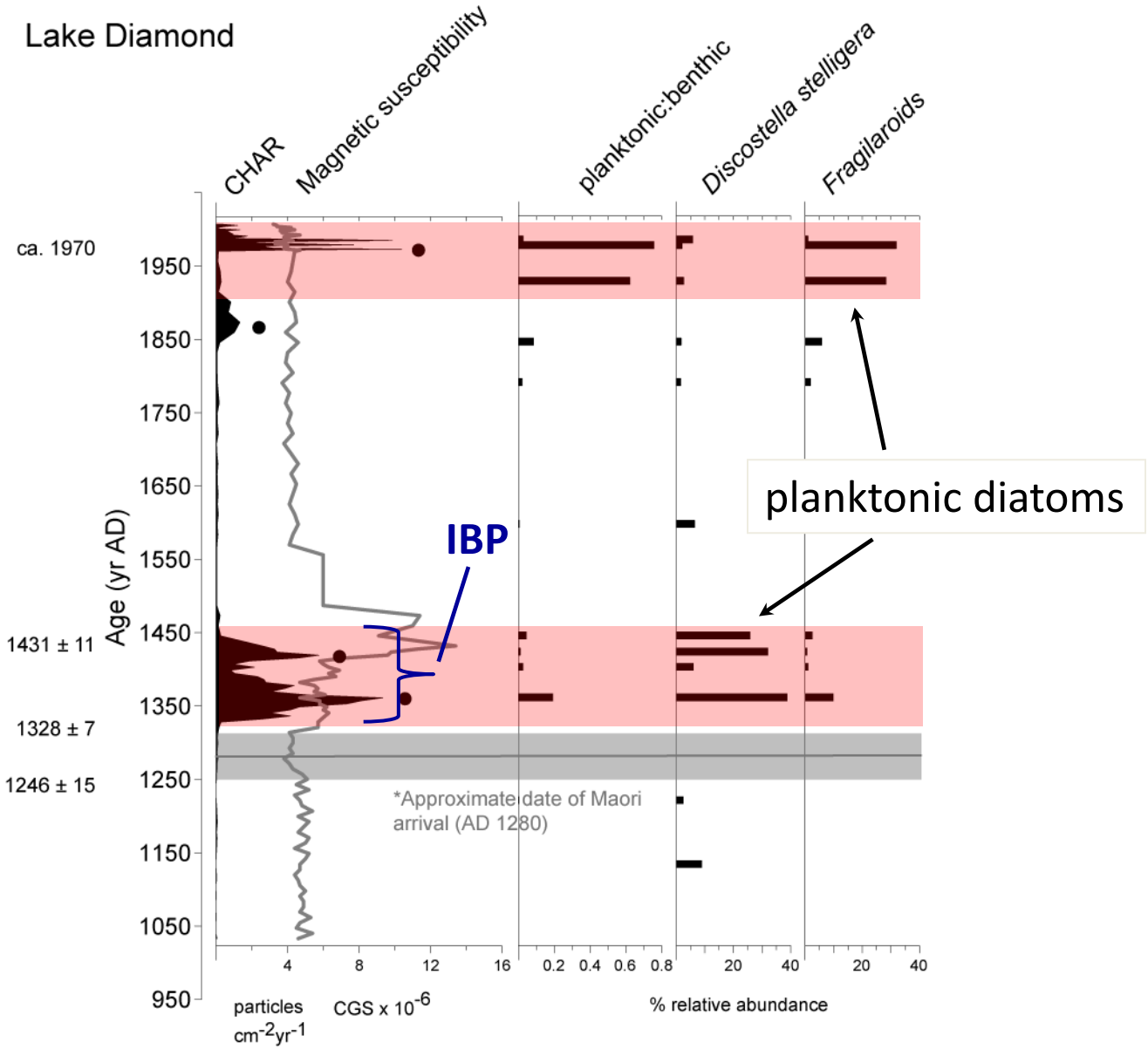
McWethy et al. 2010, Lorrey et al. 2008, Cook et al. 2006

Lake Diamond

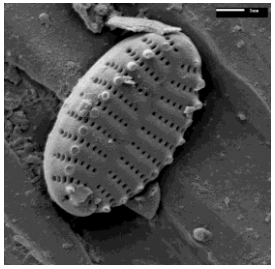


McWethy et al. 2009 The Holocene

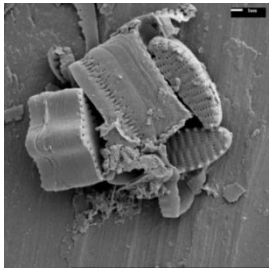
Ecological Consequences:



Diatoms



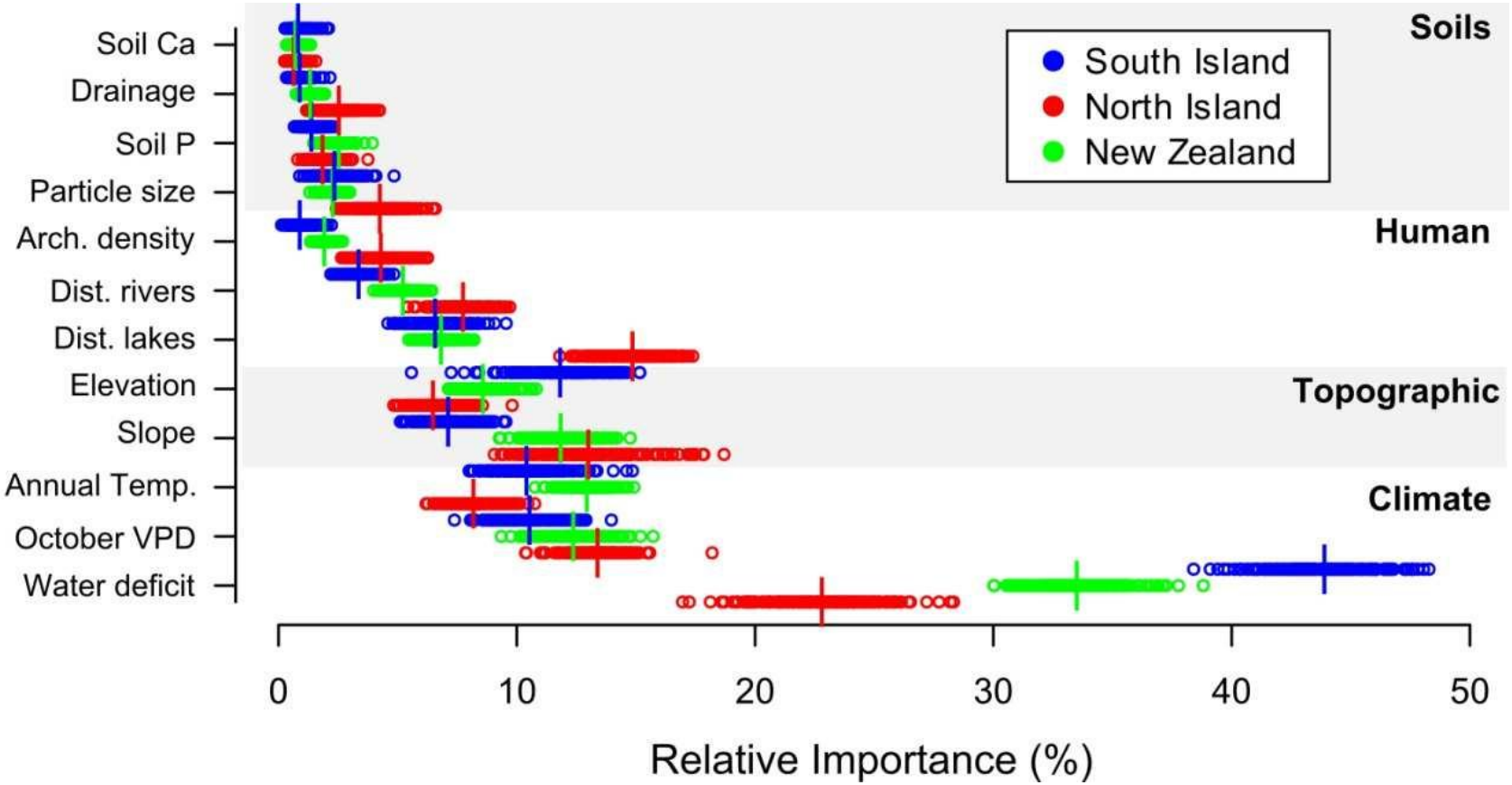
Staurosira construens



Pseudostaurosira pseudoconstruens

Closed forest to open shrubland

What variables best explain forest loss?



Perry et al., in review

What variables best explain forest loss?

North Island

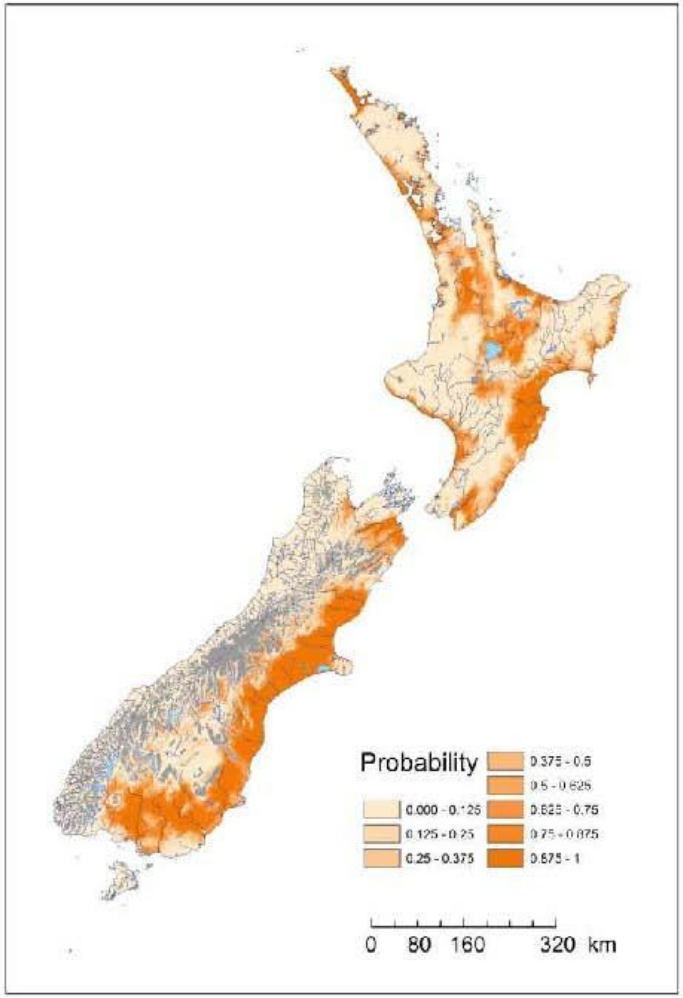
- Climate – water deficit
- Humans – proximity to lakes

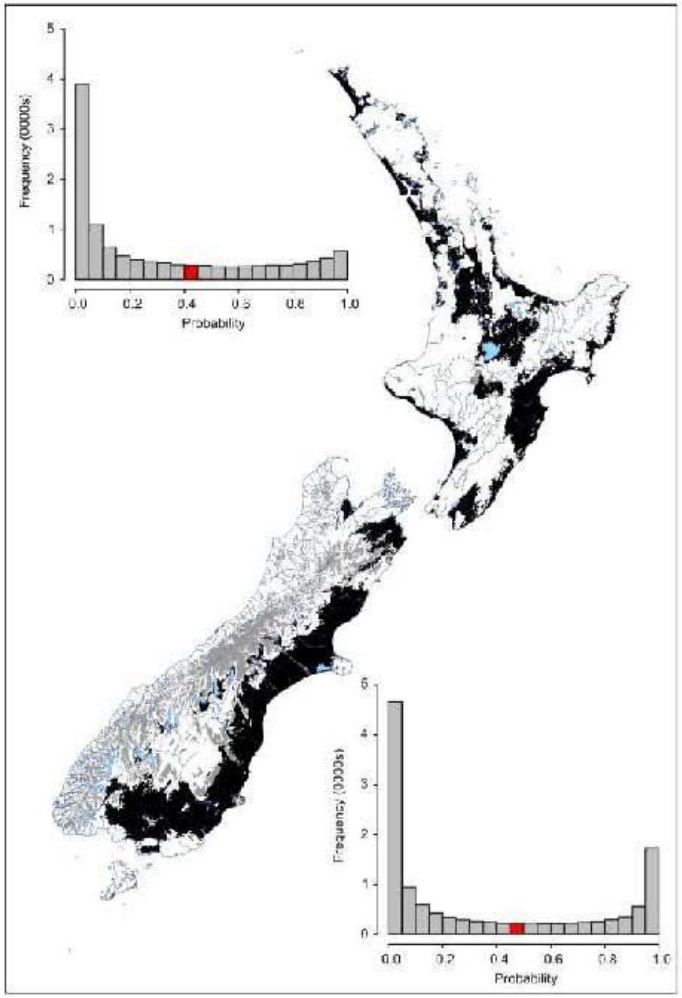
South Island

- Climate – water deficit

Perry et al., in review

Vulnerability – dry, lowland forests near lakes





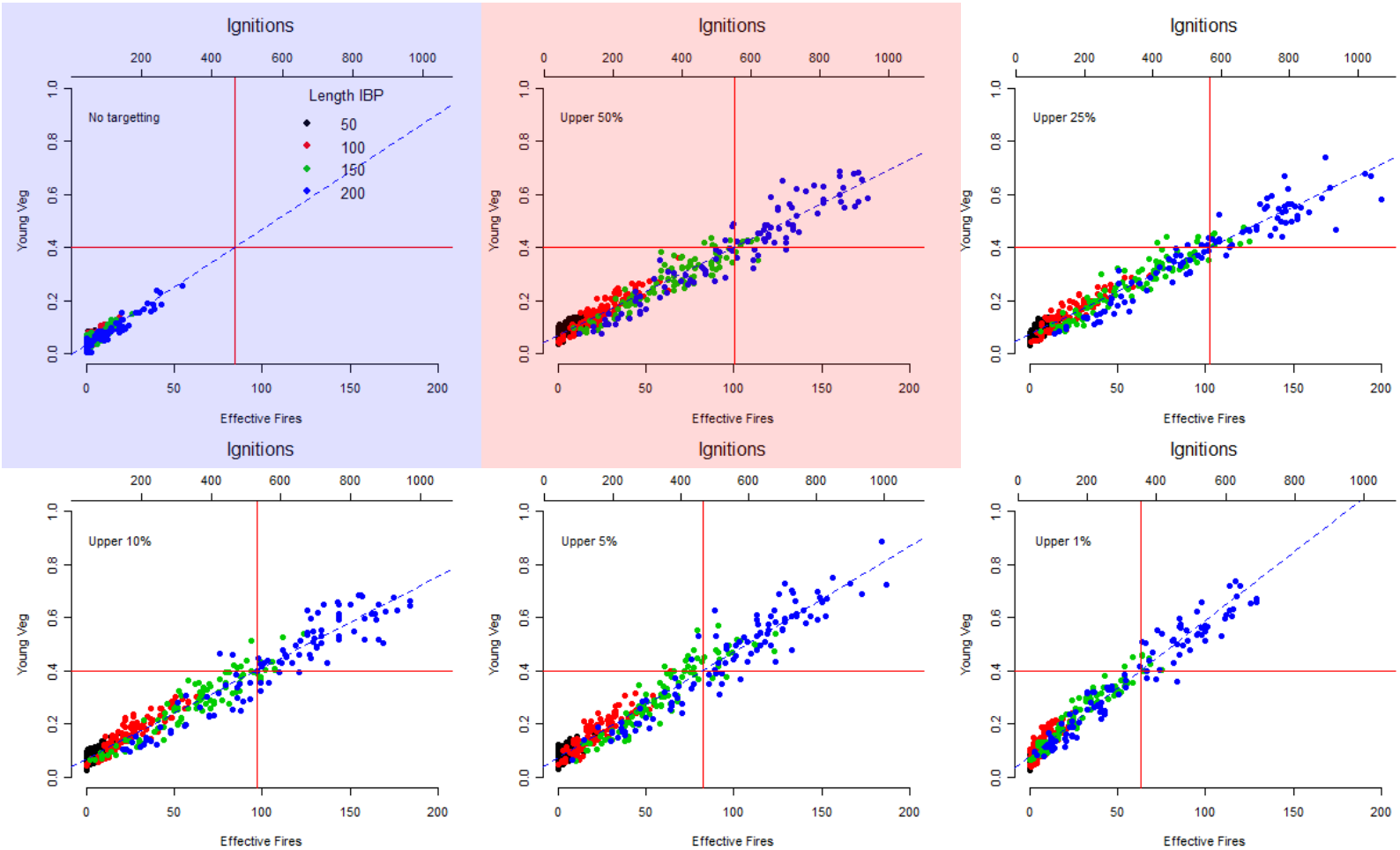
Perry et al., in review

How did small populations burn large landscapes of wet forest?

Bowen et al. in prep

Feedbacks:

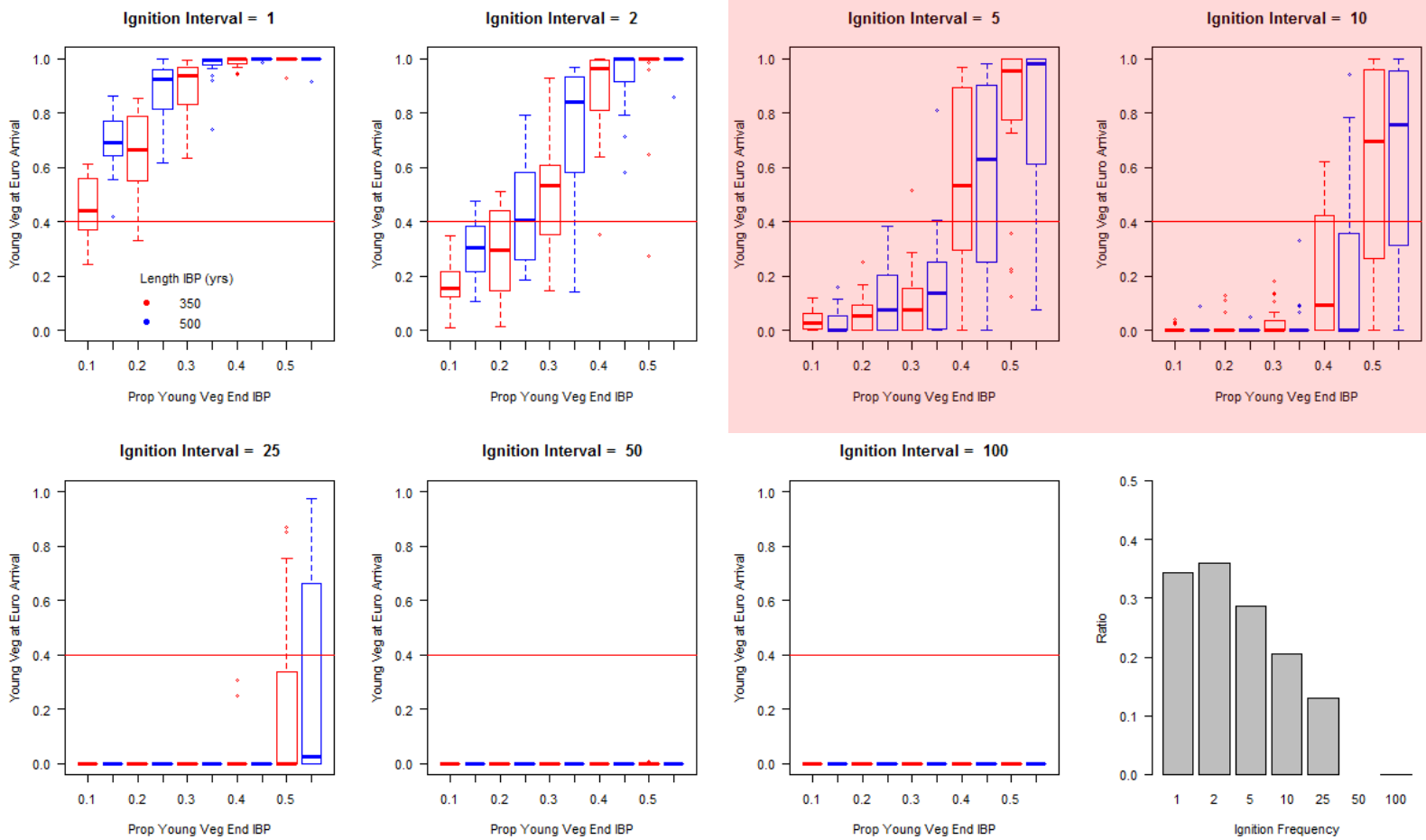
Targeting ignitions in young vegetation (flammable) results in transformation



Perry et al., in prep

Feedbacks:

Targeted decadal fires sufficient to transform landscape



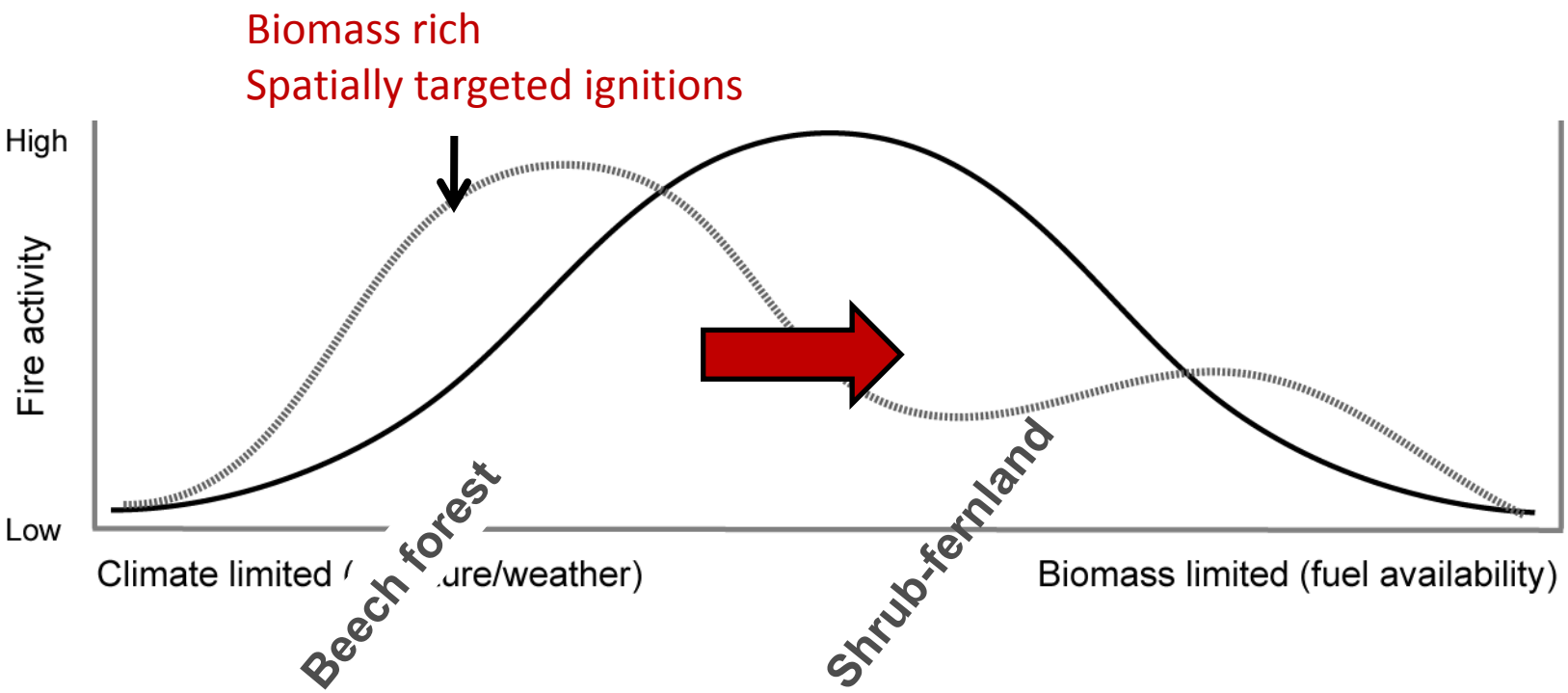
Perry et al., in prep

Fire begets fire:

- Targeting ignitions in young vegetation (highly flammable) result in high conversion
- Ignitions once every 5-10 yrs. over a 100-200 yr. interval in early seral veg. results in >40% deforestation

Perry et al., in prep

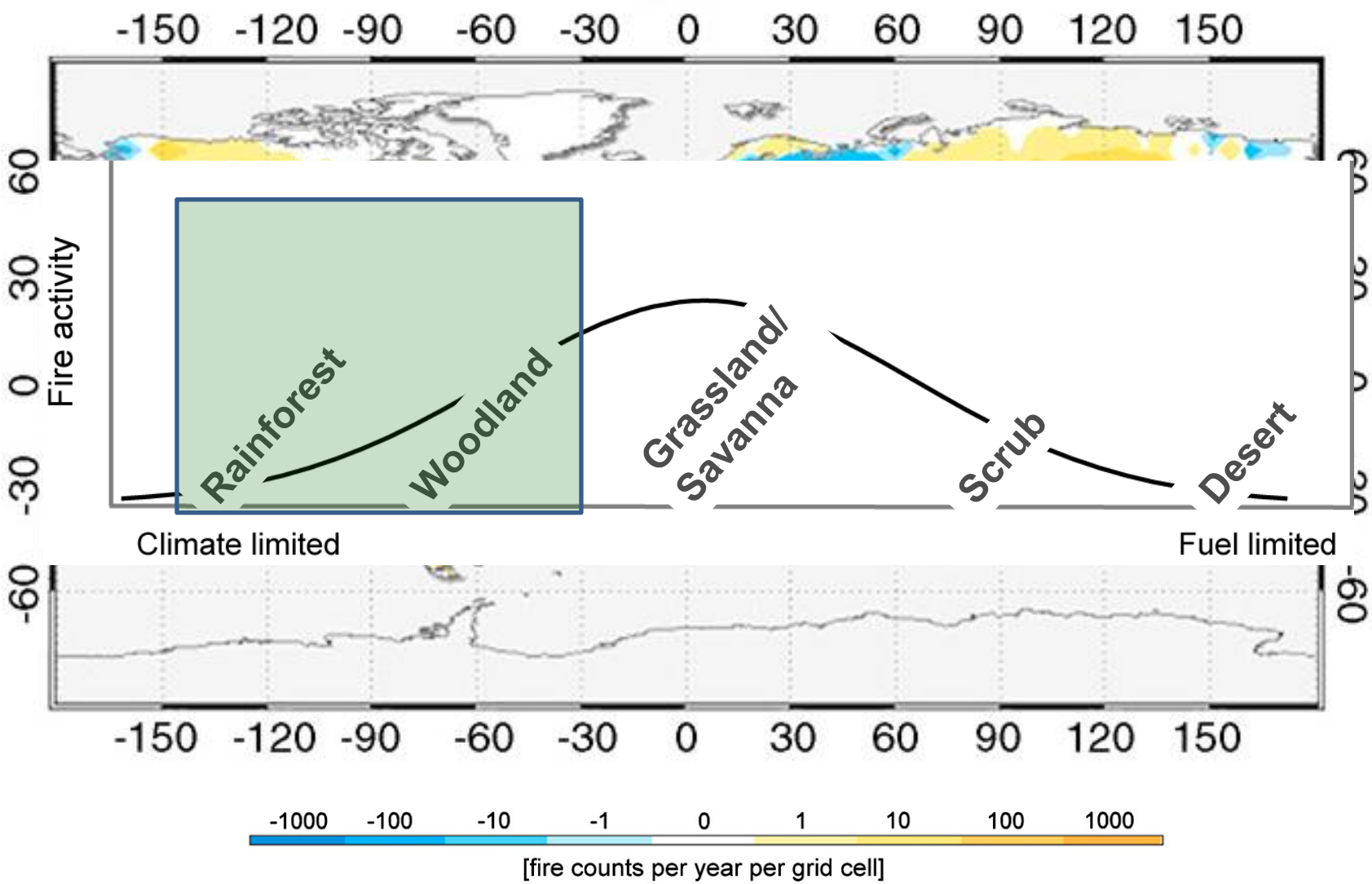
Feedbacks and consequences: human impacts



Important lessons from New Zealand

- Biomass rich/ignition-limited forests of New Zealand were vulnerable to human activity
- New Zealanders transformed landscape through targeted burning in young and flammable vegetation
- Even small populations of hunter-gatherers can transform large landscapes

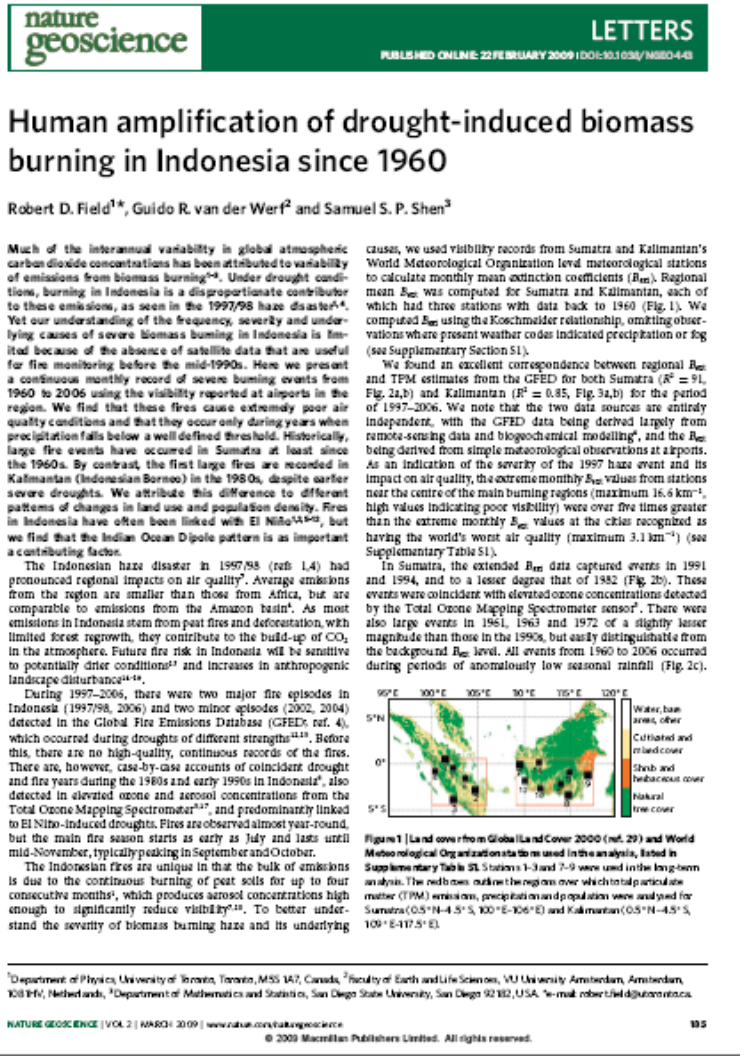
Implications for similar fuel-rich ecosystems



Pechony and Shindell 2010

Mega fires related to ENSO + Human activity

- **1997-98 El Nino event SE Asia and NE Australia**
- **Shift in rainfall patterns result in warm, dry conditions**
- **Weakening climatic controls + forest clearing = Megafires**
- **5 million ha impacted in Indonesia**



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Human amplification of drought-induced biomass burning in Indonesia since 1960

Robert D. Field[1]*, Guido R. van der Werf[2] and Samuel S. P. Shen[3]

Much of the interannual variability in global atmospheric carbon dioxide concentrations has been attributed to variability of emissions from biomass burning[1–4]. Under drought conditions, burning in Indonesia is a disproportionate contributor to these emissions, as seen in the 1997/98 haze disaster[1,4]. Yet our understanding of the frequency, severity and underlying causes of severe biomass burning in Indonesia is limited because of the absence of satellite data that are useful for fire monitoring before the mid-1990s. Here we present a continuous monthly record of severe burning events from 1960 to 2006 using the visibility reported at airports in the region. We find that these fires cause extremely poor air quality conditions and that they occur only during years when precipitation falls below a well defined threshold. Historically, large fire events have occurred in Sumatra at least since the 1960s. By contrast, the first large fires are recorded in Kalimantan (Indonesian Borneo) in the 1980s, despite earlier severe droughts. We attribute this difference to different patterns of changes in land use and population density. Fires in Indonesia have often been linked with El Niño[5,6,8–10], but we find that the Indian Ocean Dipole pattern is as important a contributing factor.

The Indonesian haze disaster in 1997/98 (refs 1,4) had pronounced regional impacts on air quality[5]. Average emissions from the region are smaller than those from Africa, but are comparable to emissions from the Amazon basin[4]. As most emissions in Indonesia stem from peat fires and deforestation, with limited forest regrowth, they contribute to the build-up of CO_2 in the atmosphere. Future fire risk in Indonesia will be sensitive to potentially drier conditions[11] and increases in anthropogenic landscape disturbance[12–16].

During 1997–2006, there were two major fire episodes in Indonesia (1997/98, 2006) and two minor episodes (2002, 2004) detected in the Global Fire Emissions Database (GFED; ref. 4), which occurred during droughts of different strengths[11,13]. Before this, there are no high-quality, continuous records of the fires. There are, however, case-by-case accounts of coincident drought and fire years during the 1980s and early 1990s in Indonesia[6], also detected in elevated ozone and aerosol concentrations from the Total Ozone Mapping Spectrometer[17,7], and predominantly linked to El Niño-induced droughts. Fires are observed almost year-round, but the main fire season starts as early as July and lasts until mid-November, typically peaking in September and October.

The Indonesian fires are unique in that the bulk of emissions is due to the continuous burning of peat soils for up to four consecutive months[1], which produces aerosol concentrations high enough to significantly reduce visibility[7,18]. To better understand the severity of biomass burning haze and its underlying causes, we used visibility records from Sumatra and Kalimantan's World Meteorological Organization level meteorological stations to calculate monthly mean extinction coefficients (B_{ext}). Regional mean B_{ext} was computed for Sumatra and Kalimantan, each of which had three stations with data back to 1960 (Fig. 1). We computed B_{ext} using the Koschmieder relationship, omitting observations where present weather codes indicated precipitation or fog (see Supplementary Section S1).

We found an excellent correspondence between regional B_{ext} and TPM estimates from the GFED for both Sumatra ($R^2 = 91$, Fig. 2a,b) and Kalimantan ($R^2 = 0.85$, Fig. 3a,b) for the period of 1997–2006. We note that the two data sources are entirely independent, with the GFED data being derived largely from remote-sensing data and biogeochemical modelling[4], and the B_{ext} being derived from simple meteorological observations at airports. As an indication of the severity of the 1997 haze event and its impact on air quality, the extreme monthly B_{ext} values from stations near the centre of the main burning regions (maximum 16.6 km^{-1}, high values indicating poor visibility) were over five times greater than the extreme monthly B_{ext} values at the cities recognized as having the world's worst air quality (maximum 3.1 km^{-1}) (see Supplementary Table S1).

In Sumatra, the extended B_{ext} data captured events in 1991 and 1994, and to a lesser degree that of 1982 (Fig. 2b). These events were coincident with elevated ozone concentrations detected by the Total Ozone Mapping Spectrometer sensor[7]. There were also large events in 1961, 1963 and 1972 of a slightly lesser magnitude than those in the 1990s, but easily distinguishable from the background B_{ext} level. All events from 1960 to 2006 occurred during periods of anomalously low seasonal rainfall (Fig. 2c).

Figure 1 | Land cover from Global Land Cover 2000 (ref. 29) and World Meteorological Organization stations used in the analysis, listed in Supplementary Table S1. Stations 1–3 and 7–9 were used in the long-term analysis. The red boxes outline the regions over which total particulate matter (TPM) emissions, precipitation and population were analysed for Sumatra (0.5° N–4.5° S, 100° E–106° E) and Kalimantan (0.5° N–4.5° S, 109° E–117.5° E).

[1]Department of Physics, University of Toronto, Toronto, M5S 1A7, Canada, [2]Faculty of Earth and Life Sciences, VU University Amsterdam, Amsterdam, 1081 HV, Netherlands, [3]Department of Mathematics and Statistics, San Diego State University, San Diego 92182, USA. *e-mail: robert.field@utoronto.ca.

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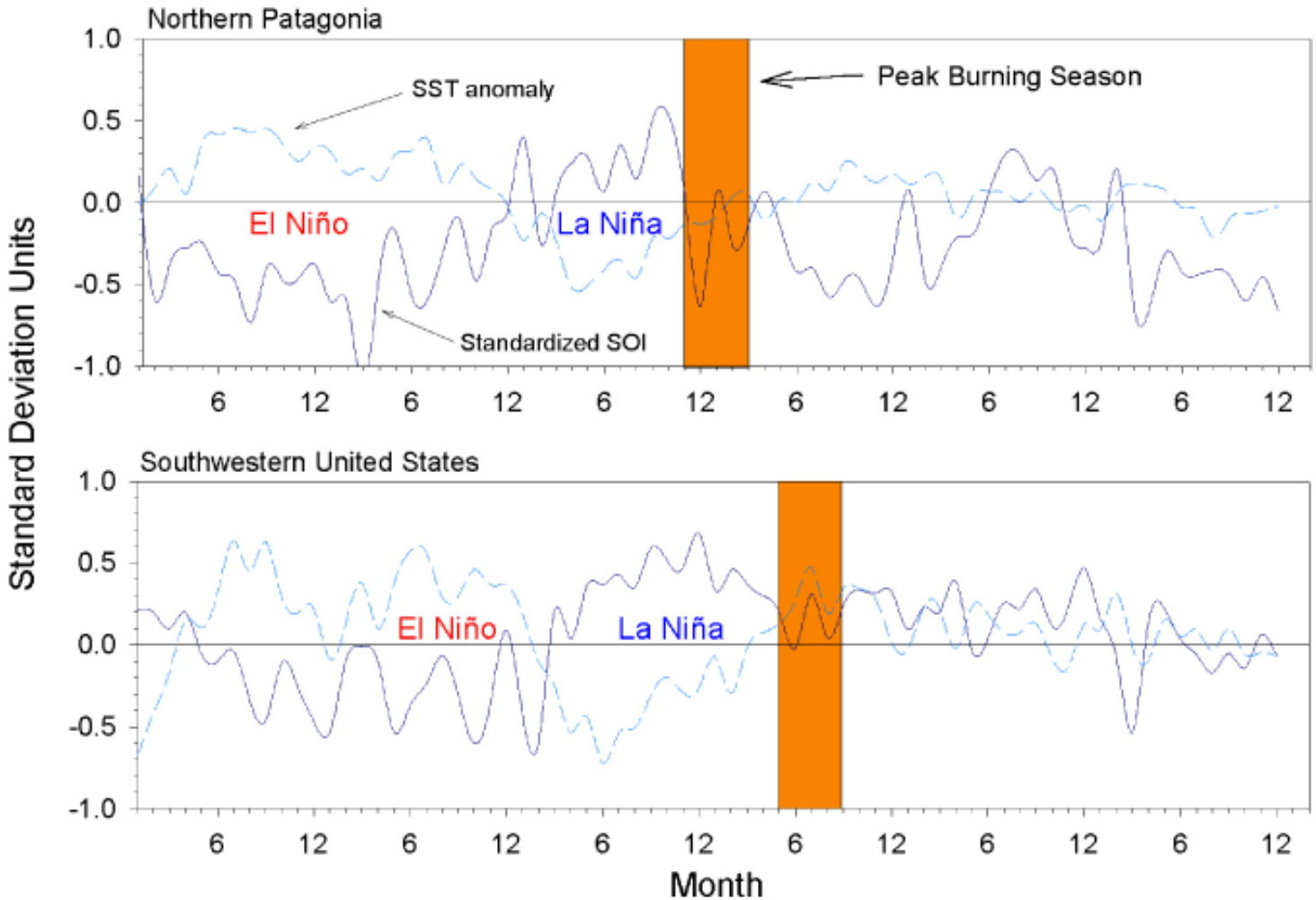
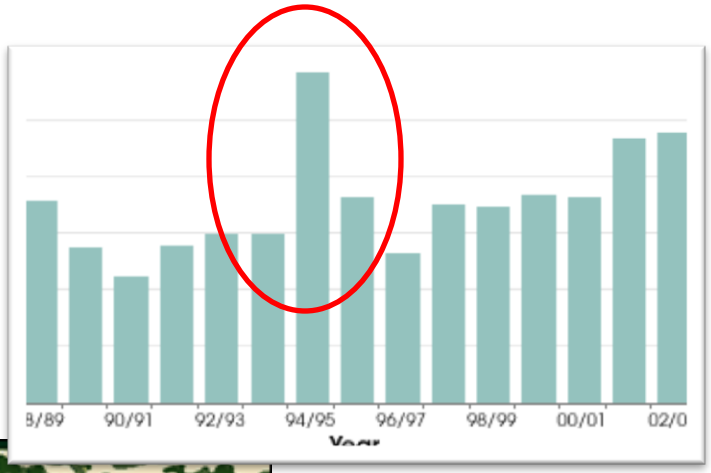
Haberle et al. 2010, Field et al. 2009, Perry and Enright 2002

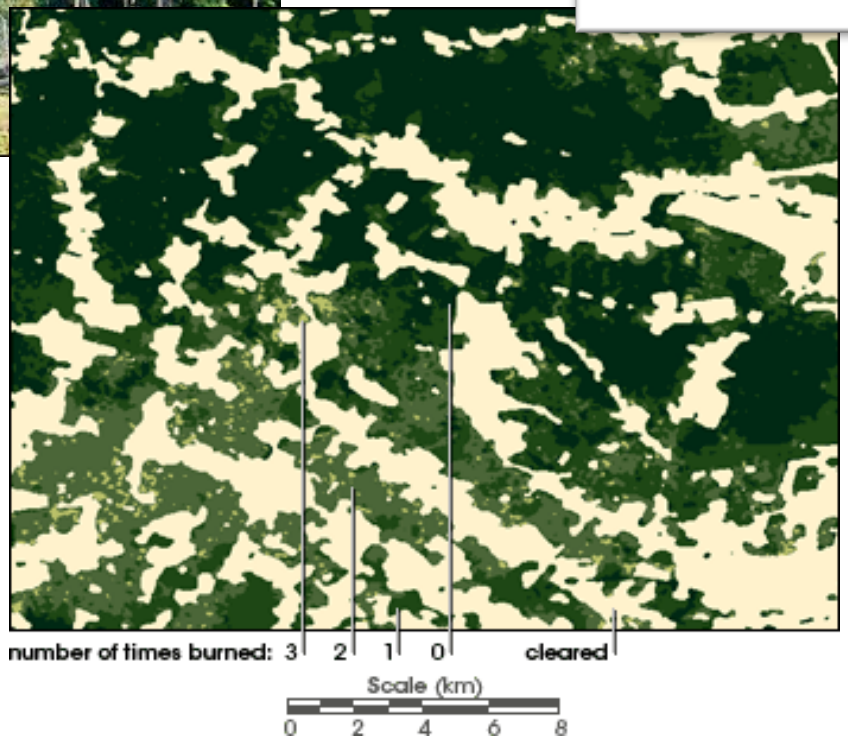
Synchronous fires in Northern Patagonia and Southwestern US



Kitzberger et al. 2001, 2002

Amazonia: 1994-95 ENSO events



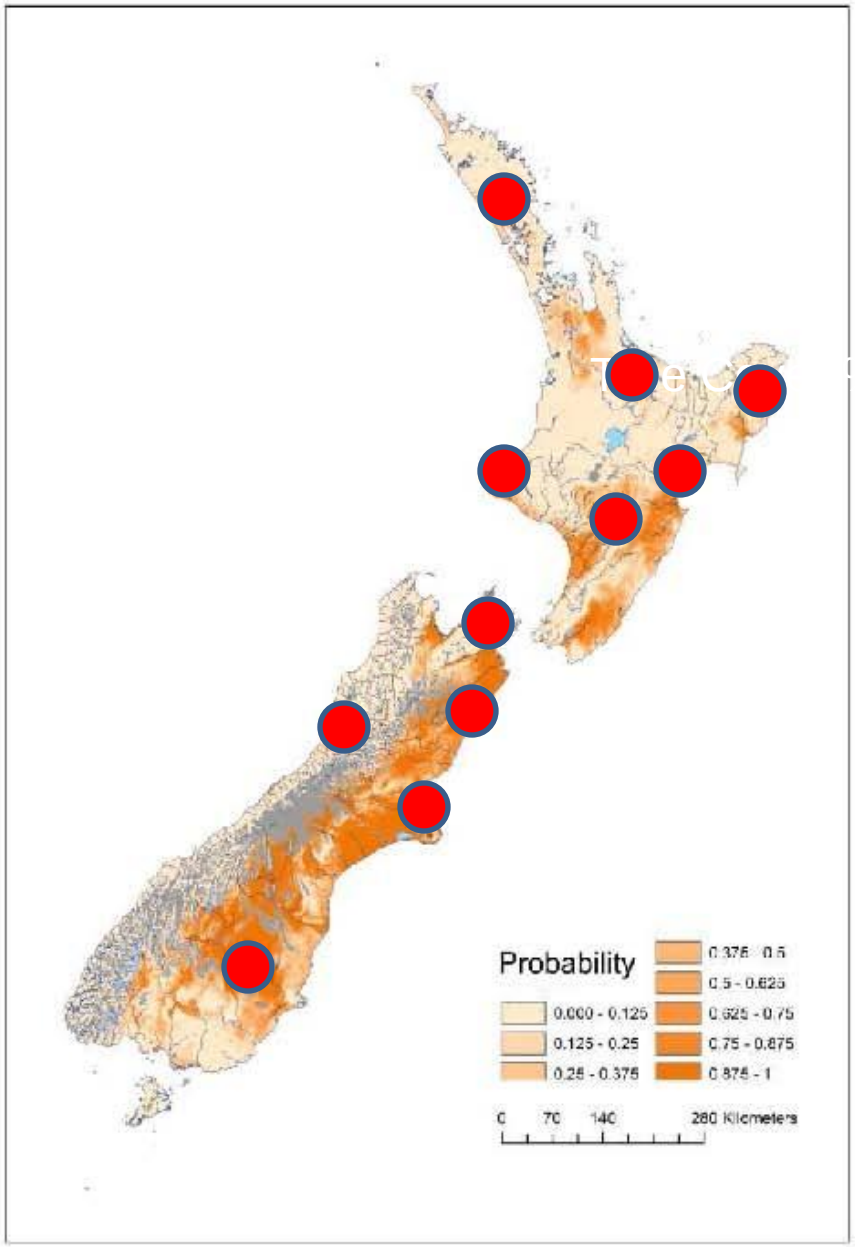


Nepstad et al. 2001; Nepstad et al. 1999; Cochrane, et al. 1999

Important conclusions

1. Biomass rich and ignition limited systems most vulnerable to human activity and changing climate
2. Even small groups of people can transform landscapes in these settings
3. Recent mega-fires appear linked to human activity + weakening climate controls (ENSO) and will likely result in more & larger fires

Next steps:



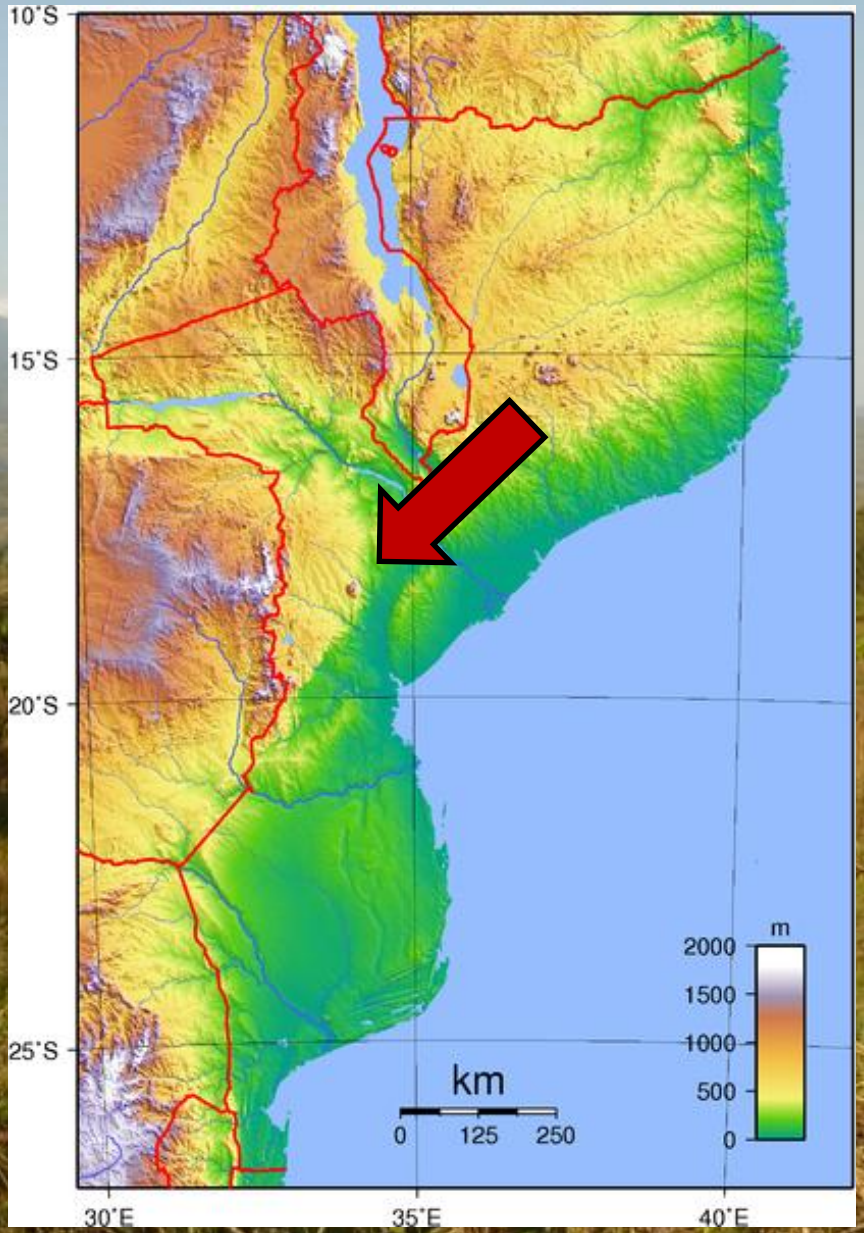
2012 fieldwork in NZ

- coastal sites near settlements
- anomalous forest loss

Flinder's Island, Tasmania

Human occupation ~30,000-5,000 yrs. ago
No presence ~5,000-200 yrs. ago

Human-climate-fire linkages: Mt. Gorongosa, central Mozambique



Are montane grasslands a consequence of human or natural fires?

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Landcare Research
Manaaki Whenua
Questions?