

Impacts of extreme environmental events upon species and ecosystems

Brian Huntley

Outline

- General characteristics of extreme environmental events that impact upon species and ecosystems
- General types of response of species and ecosystems to extreme environmental events
- Examples of responses of species and ecosystems to extreme environmental events in the recent and recorded historical past
- Examples of responses of species and ecosystems to extreme environmental events during the late Quaternary period
- General conclusions – the importance of extreme environmental events for species and ecosystems

Extreme environmental events

Extreme environmental events

- Three general types of event impact upon species and/or ecosystems
 - Type 1: Short-lived extreme excursions from their mean value(s) of one or more environmental variable(s) to which species and/or ecosystems are sensitive
 - Type 2: Relatively persistent shifts in the mean value(s) of one or more environmental variable(s) to which species and/or ecosystems are sensitive
 - Type 3: Exposure of species and/or ecosystems to some environmental factor or condition to which they are not 'normally' exposed, but to which they are sensitive

Examples of Type 1 events

- Windstorms and hurricanes
- Extreme low temperatures
- Prolonged duration of snow cover
- Prolonged droughts
 - events may occur over as little as a few hours – e.g. an extreme windstorm – or may extend over days, weeks, months, years – e.g. multi-annual droughts.

Examples of Type 2 events

- Persistent shifts in mean (seasonal) temperatures
- Persistent shifts in mean (seasonal) precipitation
 - the event is the shift
 - this usually occurs in a decade or less, although some palaeoenvironmental shifts may have extended over longer periods
 - the new conditions must generally persist for at least some years, and more usually for decades to centuries

Examples of Type 3 events

- Deposition of tephra (volcanic ash)
- Wildfire
- Snow falls in regions where they do not normally occur
 - events typically occur and/or extend over periods of only hours to a few days

Responses of species and ecosystems

Responses of species and ecosystems

- Two general classes of response
 - Type A: a transient response, the species or ecosystem returning to its former state some time after the perturbation caused by the extreme environmental event
 - Type B: a persistent response, the species or ecosystem shifting to a new state that endures long after the perturbation caused by the extreme environmental event
 - either type of response may be manifest as:
 - changes in the distribution and/or abundance of a species
 - changes in the composition and/or structure of an ecosystem

Examples of Type A responses

- A species may suffer reduced survival as a consequence of the extreme environmental event
 - its population thus being reduced following the event, although returning to its former levels some time later
- An ecosystem dominant species may suffer increased mortality as a consequence of the extreme environmental event
 - leading to a shift in ecosystem composition, with greater abundance of opportunist species following the event because they can utilise the ‘gaps’ resulting from mortality of the former dominant, although the latter will return to dominance as its population recovers to its former levels some time later

Examples of Type B responses

- Following an extreme environmental event
 - a species may become extinct, regionally or even globally,
 - a species may extend its distribution into, or ‘invade’, a region from which it was formerly absent
 - an ecosystem may experience a change in its dominant species
 - usually leading to further changes in its composition and/or structure

Relationship between event and response types

Response Type

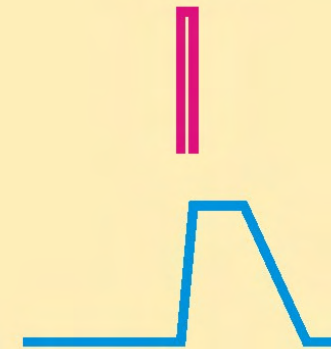
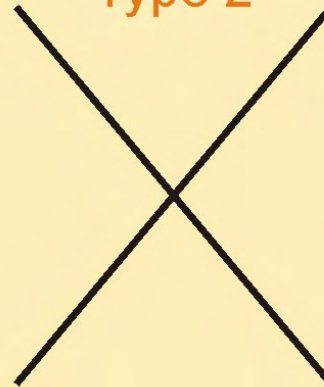
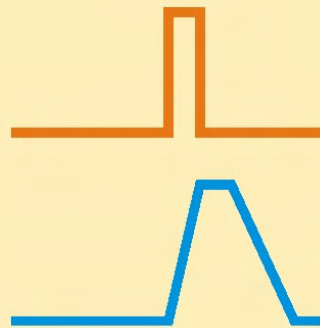
Event Type

Type A

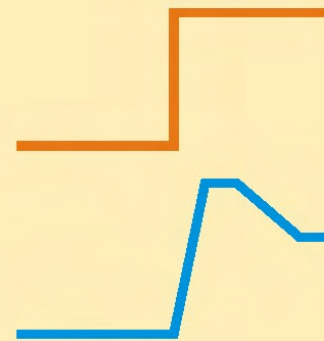
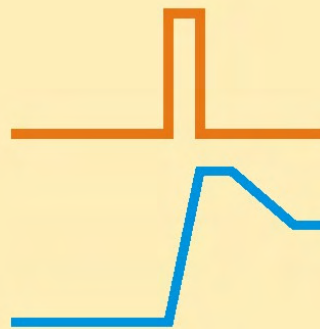
Type 1

Type 2

Type 3



Type B



Examples from the recent past

The winter of 1962–3

- Anomalously cold conditions persisted for 10 weeks
 - snow covered the ground for 40 – 70 days in many areas
 - land-fast ice and frozen shores from Hampshire to north-east England
- Impacted upon many bird species
 - much higher than average winter mortality
 - as a result both of direct effects of the low temperatures and of indirect effects of food shortages, mostly because food resources were rendered inaccessible

The winter of 1962–3

- Common Birds Census
 - marked reduction in breeding populations of a range of species in 1963 compared to 1962
 - Wren (*Troglodytes troglodytes*) :
78% reduction
 - Mistle Thrush (*Turdus viscivorus*) :
75% reduction
 - > 50% reduction
 - Moorhen (*Gallinula chloropus*)
 - Lapwing (*Vanellus vanellus*)
 - Green Woodpecker (*Picus viridis*)
 - Song Thrush (*Turdus philomelos*)
 - Pied Wagtail (*Motacilla alba*)



The winter of 1962–3

- Population reductions were transient
 - most species' populations returned to 1962 levels by 1966, i.e. within 3 years
 - worst established species took longer to recover, although principally in less favoured habitats
 - Wren, for example, had its remaining population concentrated in woodlands and waterside vegetation in 1963; it recovered in numbers relatively quickly in these habitats but more slowly in gardens, orchards and hedges that mostly had to be re-colonised

Dobinson, H.M. & Richards, A.J. (1964) The effects of the severe winter of 1962–63 on birds in Britain. *British Birds*, **57**, 373-434.

Cawthorne, R.A. & Marchant, J.H. (1980) The effects of the 1978-79 winter on British bird populations. *Bird Study*, **27**, 163-172.

The drought of 1975–6

- Over a 16-month period England had only 64% of long-term average rainfall
 - June – August 1976 rainfall was only 37% of the long-term average
- High levels of mortality of plant species in grasslands on shallow soils
- High levels of mortality of Beech (*Fagus sylvatica*) trees in woodlands on well-drained sites

The drought of 1975–6

- Chalk grassland in south-east England badly affected
 - 39·2% bare ground in summer 1976; mean for 1973–5 5·5%
 - dominant grass, Sheep's Fescue (*Festuca ovina*), summer cover reduced to 19·1% from a mean of 47·1% for 1973–5
 - cover of mosses only 2·2%, compared to a mean of 11·1% for 1973–5

The drought of 1975–6

- September 1976 rainfall was *ca.* 140% of the long-term mean
 - recovery of many species was rapid – either by vegetative growth or establishment of seedlings
 - bare ground that autumn decreased to 14%, not much more than the mean of 10% for 1973–5
 - Sheep's Fescue was slow to recover
 - proportion of annual species in the sward in autumn 1976 was correspondingly higher than 'normal'
 - community composition took a few years to return to its previous state

The drought of 1975–6

- Impacts on Beech trees
 - many mature trees killed immediately or severely damaged
 - growth of surviving trees negligible until about 1985
 - had still not recovered to pre-drought rates after 15 years
 - damaged trees still dying from drought-induced damage 15 years later
 - through its effects on Beech, the drought had a marked impact on the structure and composition of the woodland
 - the long-term outcome remains unclear, although rapid growth of sub-canopy Beech after 1983 in parts of the wood that suffered most canopy mortality suggests a Type A response will eventually be apparent



The 'hurricane' of October 16th 1987

- A severe windstorm across southern England
 - destroyed *ca.* 15 million trees
 - 16,000 ha of woodland so damaged that the areas were subsequently cleared completely
 - many severely damaged sites were managed, often plantation woodlands, and were re-planted
 - some sites, principally semi-natural woodlands, allowed to regenerate naturally

The 'hurricane' of October 16th 1987

- 20 naturally regenerating sites surveyed in autumn–winter 2002–3
 - trees regenerating at all 20 sites
 - 22 species of tree in all recorded regenerating
 - Birch (*Betula* sp.) most frequent
 - regenerating trees 3–7 m tall at most sites, up to 10–11 m at a minority of sites
 - at most sites the most abundant regenerating species did not include the species dominating the woodland before the storm



Windstorm of 1795 at Fiby Urskog

- Fiby Urskog
 - old-growth boreal forest
 - never logged
 - largely dominated by Norway Spruce (*Picea abies*)
- Windstorm in 1795
 - present canopy represents the end-point of the response to that event
 - but also reflects a general reduction in fire frequency after that time
 - Norway Spruce previously a minor canopy component



Examples from the palaeoecological record

The 8.2 ka event

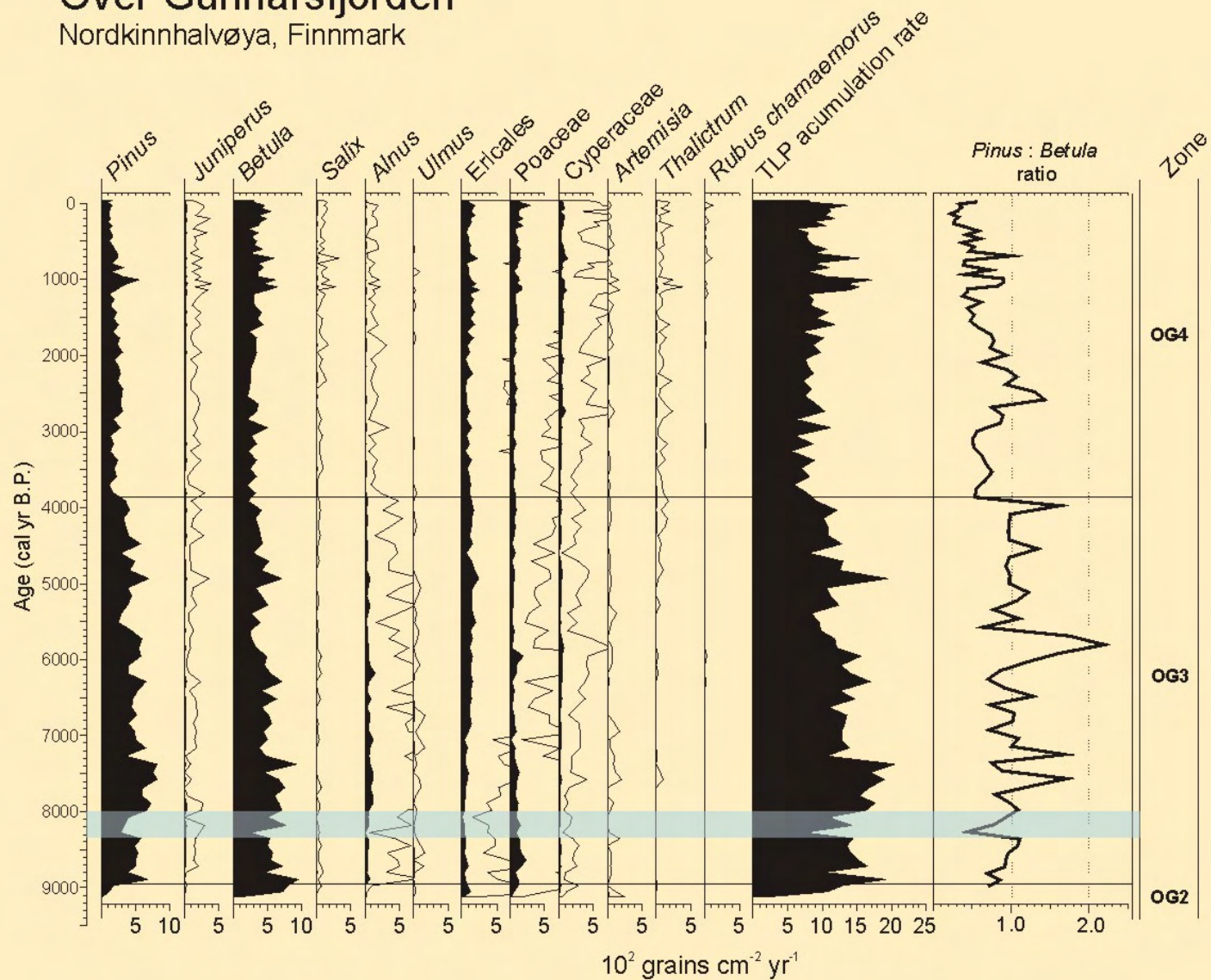
- Most extreme climatic event, at least around the North Atlantic, since the Holocene began
 - ice-core evidence from Greenland indicates 6°C cooling at the peak of the event
 - about half the magnitude of cooling between the late-glacial interstadial (Allerød) and the Younger Dryas
 - coldest conditions persisted for *ca.* 100 yr
- Palaeovegetation records document ecosystem responses to this event

The 8.2 ka event

- Finnmark
 - southward retreat of Scots Pine (*Pinus sylvestris*) from its northern limit
 - marked reduction in pollen productivity of the vegetation generally

Over Gunnarsfjorden

Nordkinnhalvøya, Finnmark



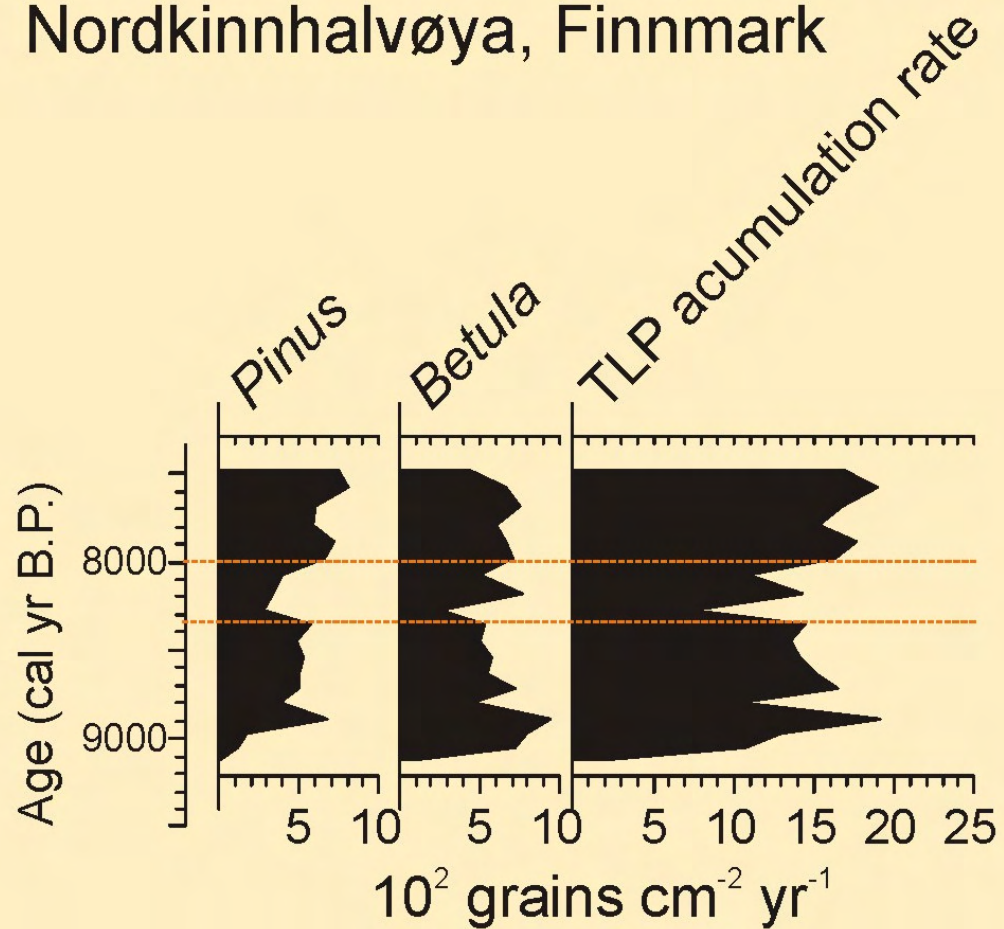
Durham
University

Allen, J.R.M., Long, A.J., Ottley, C.J., Pearson, D.G. & Huntley, B. (2007) Holocene climate variability in northernmost Europe. *Quaternary Science Reviews*, **26**, 1432-1453.

School of Biological and Biomedical Sciences

Over Gunnarsfjorden

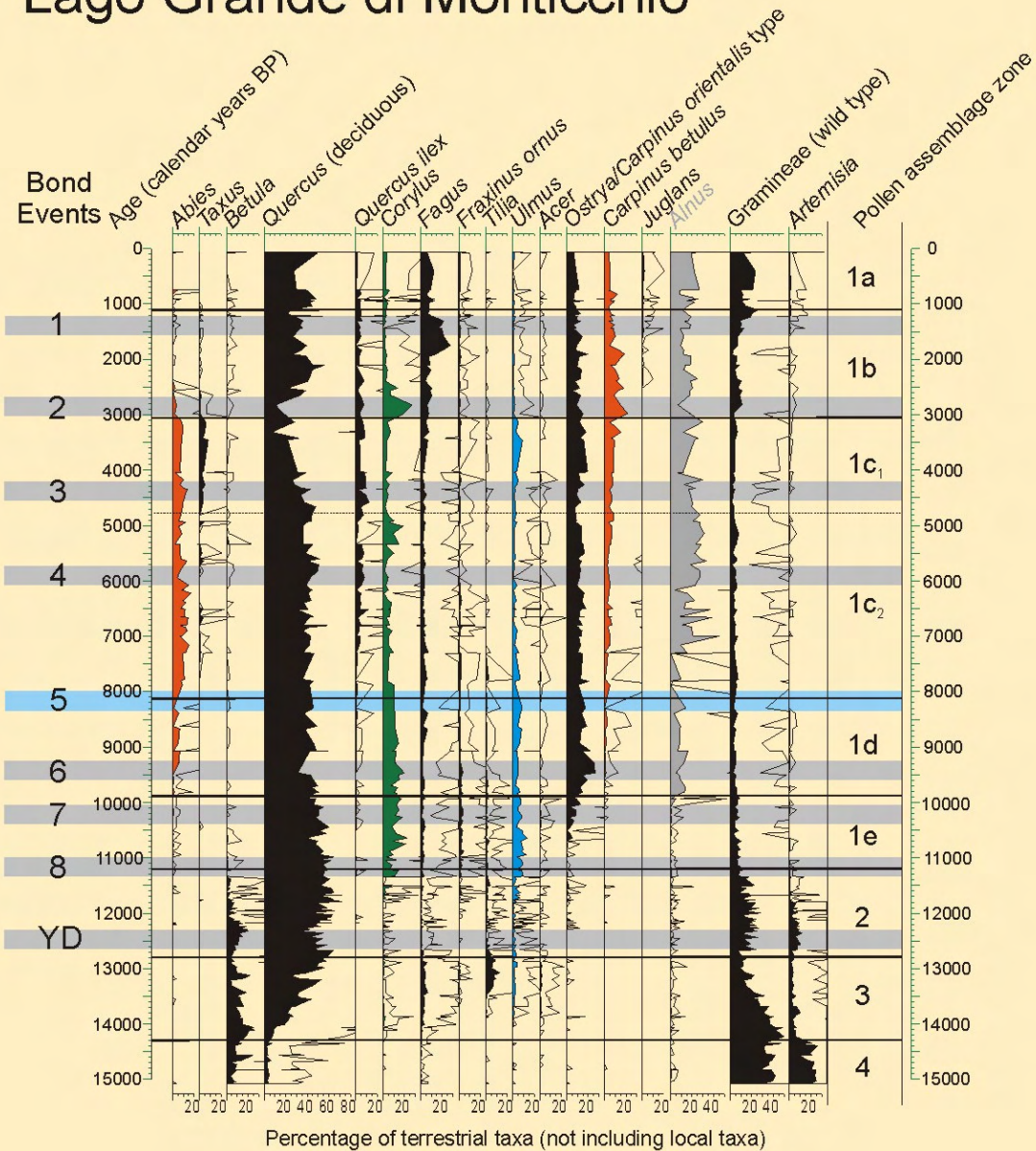
Nordkinnhalvøya, Finnmark



The 8.2 ka event

- Southern Italy
 - marked change in forest composition
 - Elm (*Ulmus*) and Hazel (*Corylus*) prominent forest components prior to this time, but reduced in abundance thereafter
 - Fir (*Abies*) and Hornbeam (*Carpinus betulus*) relatively infrequent forest components prior to this time, but increase in abundance and persist as important forest components thereafter

Lago Grande di Monticchio



Allen, J.R.M., Watts, W.A., McGee, E. & Huntley, B. (2002) Holocene environmental variability - the record from Lago Grande di Monticchio, Italy. *Quaternary International*, **88**, 69-80.

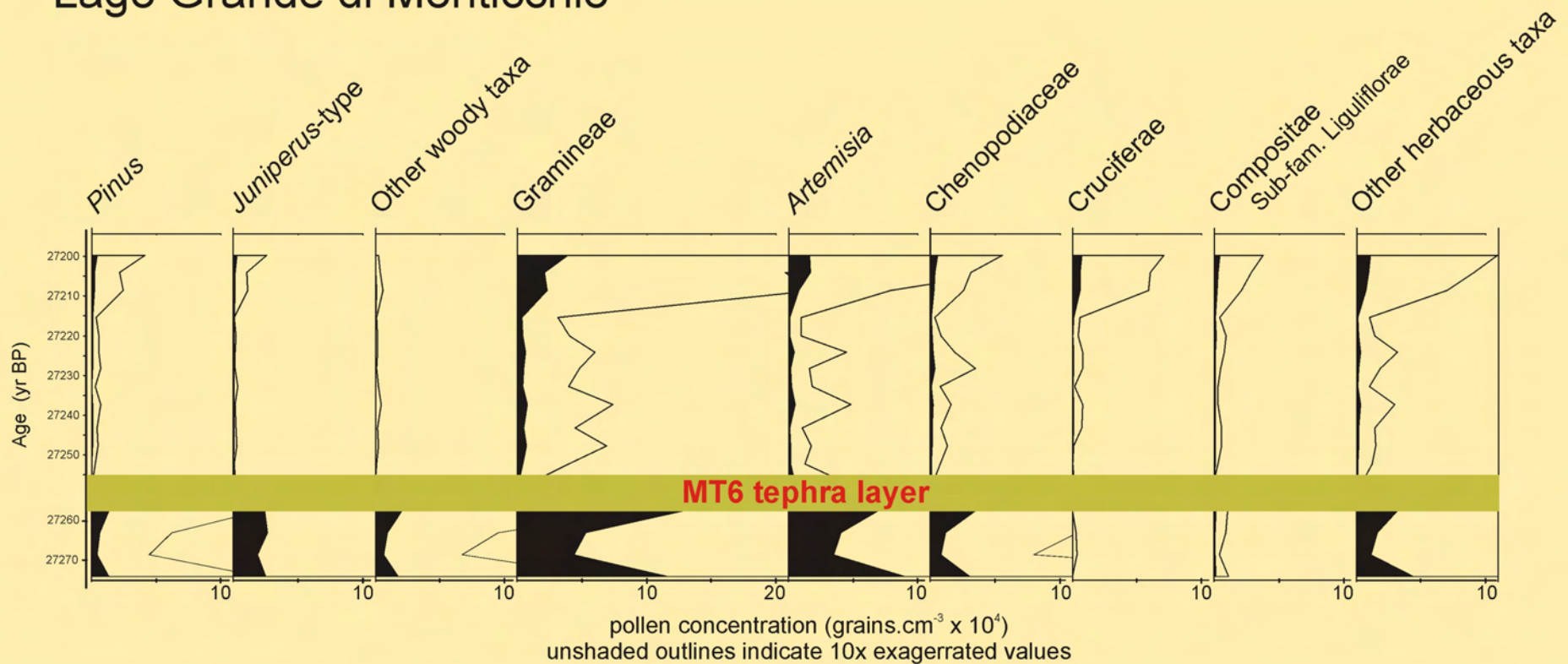
Tephra deposition

- Lago Grande di Monticchio
 - sedimentary record spans almost 140 ka
 - numerous tephra deposition events
 - easily recognised in the sedimentary record
 - discrete events occurring almost instantaneously in terms of the length of the record
 - sediments in large part annually-laminated
 - enables very precise chronology
 - fine-resolution sampling (1–2 mm)
 - enables sampling of the year following tephra deposition and at intervals of 1–2 years thereafter

Tephra deposition

- Lago Grande di Monticchio
 - predominant vegetation ranges from closed forest, through open savanna-like woodlands, to steppe-like grassland and herbaceous communities
 - example of tephra fall 27,256 yr BP (MT6 tephra)
 - steppe vegetation with Juniper (*Juniperus*) predominated prior to tephra deposition
 - tephra layer in lake sediment 28.6 cm thick
 - tephra originates from the Campi Flegrei volcanic region of western Italy; it is an acidic K-trachyte tephra
 - MT6 tephra has been correlated with marine tephra Y3

Lago Grande di Monticchio



- marked reduction in pollen entering the lake
 - vegetation severely disrupted by the tephra fall
- pollen of *Juniperus* particularly reduced in abundance
 - juniper shrubs especially severely affected by the tephra
- vegetation recovery takes many decades
 - pollen accumulation rates for herbaceous taxa only begin to recover after *ca.* 40 years; 56 years after tephra deposition they are still much less than prior to the tephra fall

General Conclusions

General Conclusions

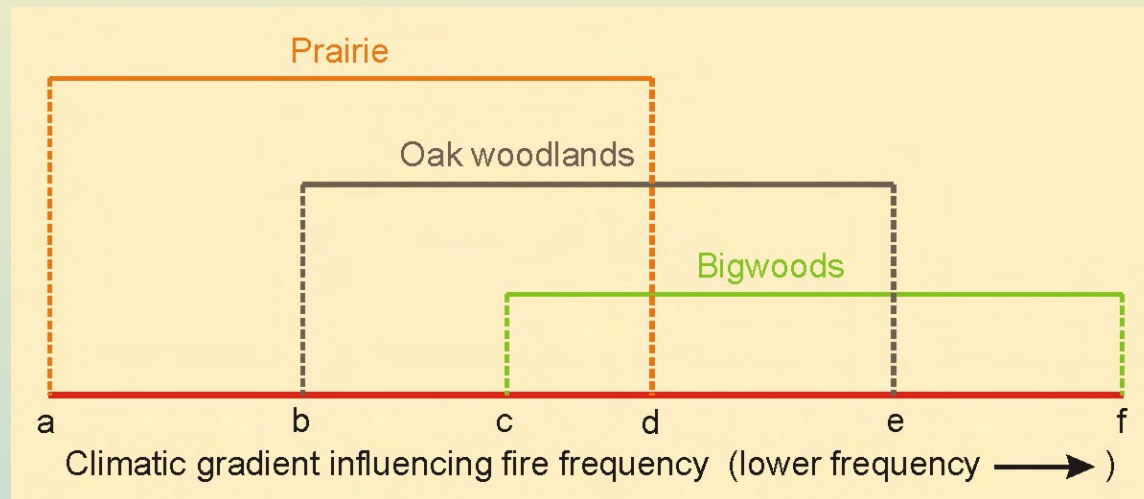
- First
 - as proposed, both Type 1 and Type 3 extreme environmental events can elicit ecological responses of either Type A or Type B
 - Type 2 extreme environmental events elicit only Type B ecological responses
 - e.g. rapid large-magnitude warming from the Younger Dryas to the Holocene triggered major changes in the distributions and abundances of individual species, as well as in ecosystem composition and structure

General Conclusions

- First (cont.)
 - Type 1 events elicit Type B responses at least in part because of ecological inertia
 - an established ecosystem may persist even when conditions have changed sufficiently that, if the system is disturbed, the subsequent recovery results in an ecosystem of different composition and/or structure
 - Bradshaw – Birch and/or Scots Pine forests excluded Norway Spruce in Sweden, even after climatic conditions favoured its establishment, until disturbed (by fire, windstorm and/or insect attack)
 - Grimm – until disturbed (by fire) Prairie able to persist and exclude Oak woodlands or Bigwoods , even when climatic conditions have changed to favour their development

General Conclusions

- First (cont.)



Schematic illustration of ecological inertia

If the initial state is Prairie, developed under climatic conditions between a and b, then this will persist, in the absence of disturbance, even if climatic conditions have shifted to lie between b and d. However, following a disturbance, in this case by fire, Oak woodlands will develop if conditions lie between b and c, and Bigwoods if conditions lie between c and d. Only if conditions change to lie to the right of d, however, will the Prairie be replaced by Oak woodlands in the absence of disturbance.

(After Grimm, E.C. (1983) *New Phytologist* **93**: 311-50)

General Conclusions

- Second
 - duration of the impact of an extreme environmental event of Types 1 or 3 depends upon the longevity and/or fecundity of the species affected
 - Type A responses may take only a few years if species are relatively short-lived and fecund
 - Type A responses may take decades to centuries, however, where the ecosystems are dominated by long-lived woody taxa
 - whatever Type of extreme environmental event elicits them, Type B responses will take at least a decade, and often as much as several centuries

General Conclusions

- Third
 - extreme environmental events can lead to, or at least contribute to, the extinction of species
 - the Great Auk (*Pinguinis impennis*) became extinct in 1844, the ultimate cause being human persecution
 - a major contributory factor, however, was destruction, in 1830, of its principal remaining breeding site, the inaccessible island of Geirfuglasker, by an underwater volcanic eruption



General Conclusions

- Third (cont.)
 - extreme environmental changes probably sealed the eventual fate of many large Pleistocene mammals, their habitats largely disappearing as a result of these changes



Woolly rhinoceros
Coelodonta antiquitatis



Giant deer
Megaloceros giganteus



Woolly mammoth
Mammuthus primigenius



