# Introduction to Quaternary Palaeoecology

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Nordforsk PhD course, Abisko 2011


What is palaeoecology?

How do we do a Q-Time palaeoecological study?

Quaternary pollen analysis

Quaternary plant-macrofossil analysis

Quaternary chironomid analysis

Some examples of Q-Time palaeoecological studies

Conclusions

## What is Palaeoecology?

**Ecology** - study and understanding of complex relationships between living organisms and their present environment.

**Palaeoecology** is the ecology of the past. Linked to both biology and geology. Can be any period in earth's history. Based on fossil plants and animal remains preserved in sediments.

**Quaternary** is last 2.7 million years of earth's history. Unique for its oscillating climates, glacials and interglacials, and evolution of man.

**Palaeoecology** - in theory, study and understanding of relationships between past organisms and the environment in which they lived. **In practice**, largely concerned with reconstruction of past ecosystems. To do this, must use all available evidence (biological and geological) to reconstruct past environment.

- difficult to deduce organism-environment relationships in past because biological evidence has been used to reconstruct past environment. **Avoid circular arguments** (pollen diagram → past vegetation; past vegetation → past climate; past climate to explain changes in pollen diagram). Pollen data tell us about past vegetation **or** past environment but **not** both. Need independent evidence, e.g. from another fossil type or isotope data.

## Palaeoecology is the study of the ecology of the past

It involves:

- Reconstructing the **biota** that lived in the past (plants and animals)
- Reconstructing the **communities** that lived in the past
- Reconstructing the past **landscapes and ecosystems**
- It also involves reconstruction of past **environments**, that include climate and possible human impacts

## What is Quaternary-Time (Q-Time)?

Most ecologists interested in time-scales of days, weeks, months, years, decades, or even centuries – **Real-Time** or **Ecological-Time**

Palaeobiologists and palaeoecologists interested in time-scales of hundreds, thousands, and millions of years.

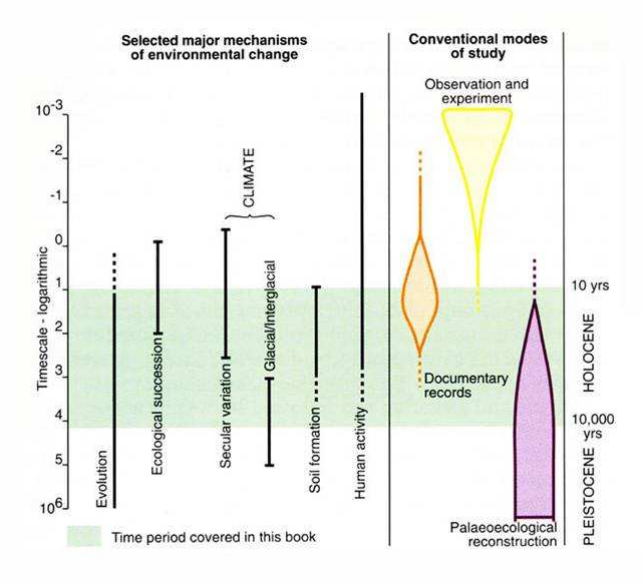
- **Deep-Time** – pre-Quaternary sediments and fossil record to study evolution and dynamics of past biota over a range of time-scales, typically >$10^6$ years.
- **Q-Time** or **Quaternary-Time** – uses tools of palaeobiology (fossils, sediments) to study ecological responses to environmental changes at Quaternary time-scales ($10^3$-$10^5$ years) during the past 2.7 million years. Concentrates on last 50,000 years, the window dateable by radiocarbon-dating. Also called Near-time (last 1-2 million years).

**Deep-Time** scientists are called **palaeontologists** or **palaeobiologists**

**Q-Time** scientists are called **Quaternary scientists** or **palaeoecologists**

**Real-Time** scientists are called **ecologists** and **biogeographers**

## Relationship between Q-Time and Real-Time




Mechanisms and modes of studying environmental change over different timescales (modified from Oldfield, 1983)

## Do Q-Time palaeoecology and plant migration, persistence, and adaptation belong together?

Quaternary palaeoecology traditionally concerned with **reconstruction** of past biota, populations, communities, landscapes (including age), environment (including climate), and ecosystems

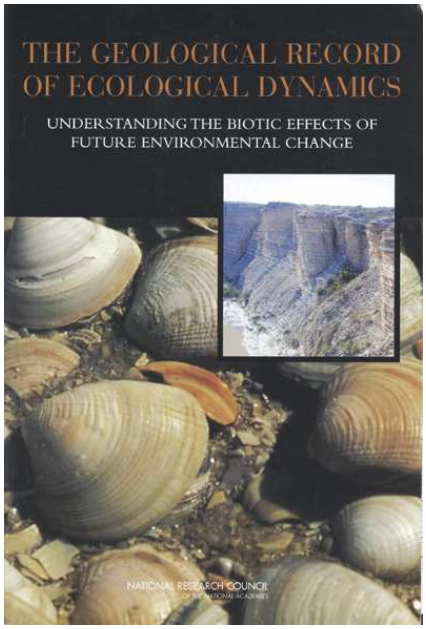
**Emphasis** on reconstruction, chronology, and correlation

Been extremely successful but all our hard-earned palaeoecological data remain a largely **untapped source** of information about how plants and animals have responded in the past to rapid environmental change

"Coaxing history to conduct experiments" E.S. Deevey (1969)

**Brilliant idea** but rarely attempted. Recently brought into focus by the Flessa and Jackson (2005) report to the National Research Council of the National Academies (USA) on The Geological Record of Ecological Dynamics

Important and critical role for palaeoecology. The Geological Record of Ecological Dynamics – Understanding the Biotic Effects of Future Environmental Change (Flessa & Jackson 2005)




Three major research priorities

1. Use the geological (= palaeoecological) record as a **natural laboratory** to explore biotic responses under a range of past conditions, thereby understanding the basic principles of biological organisation and behaviour: **The geological record as an ecological laboratory** 'Coaxing history to conduct experiments'.
2. Use the geological record to improve our ability to **predict** the **responses** of biological systems to future environmental change:
   **Ecological responses to environmental change**
3. Use the more recent geological record (e.g. mid and late Holocene and the 'Anthropocene') to evaluate the **effects of anthropogenic** and non-anthropogenic factors on the variability and behaviour of biotic systems:
   **Ecological legacies of societal activities**

Palaeoecology can also be **long-term ecology**

Basic essential **needs** in using the Q-Time palaeoecological record as a long-term ecological laboratory

1. Detailed **biostratigraphical data** of organism group of interest (e.g. plants – pollen **and** plant macrofossil data). **Biotic response** variables
2. **Independent palaeoenvironmental reconstruction** (e.g. July air temperature based on chironomids). **Predictor** variable or forcing function
3. Detailed fine-resolution **chronology**

Can look at ecological problems and biotic responses in a long-term Q-Time perspective

## Why Study Q-Time Palaeoecology?

1. Present-day ecology benefits from historical perspective

"Palaeoecology can provide the only record of complete *in situ* successions. The framework of classical succession theory (probably the most well known and widely discussed notion of ecology) rests largely upon the inferences from separated areas in different stages of a single hypothetical process (much like inferring phylogeny from the comparative analogy of modern forms). Palaeo-ecology can provide direct evidence to supplement ecological theory."

S.J. Gould (1976)

"There is scarcely a feature in the countryside today which does not have its explanation in an evolution whose roots pass deep into the twilight of time. Human hands have played a leading role in this evolutionary process, and those who study vegetation cannot afford to neglect history."

C.D. Pigott (1978)

2. Past analogue for future
3. Intellectual challenge and desire to understand our past
4. Reconstructions of past environment important to evaluate extent of natural variability
5. 'Coaxing history to conduct experiments'
6. Provides a long-term ecological observatory or 'natural laboratory' in which biotic response can be studied
7. Fun!

## Philosophy of palaeoecology

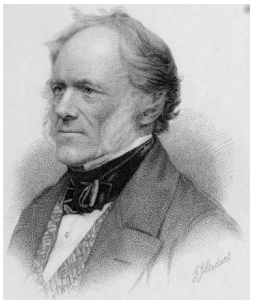
1. Descriptive historical science, depends on inductive reasoning
2. Uniformitarianism "present is key to the past"
3. Method of multiple working hypotheses
4. Simplicity – Ockham's razor
5. Sound taxonomy essential
6. Language – largely biological and geological
7. Data frequently quantitative and multivariate

## Uniformitarianism

James Hutton, 1788; John Playfair, 1802; Charles Lyell, 1830; Archibald Geikie, 1882

**Basic assumption** and **philosophical principle** of palaeoecology

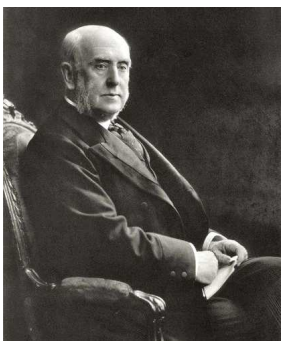
**'The present is the key to the past'**



**Charles Lyell** (1797-1875) Scottish geologist and also botanist

*Principles of Geology* (1830-33)

Presented idea of uniformitarianism to propose that **processes** at work today have operated over the immense span of geological time but that the **rates** may have changed



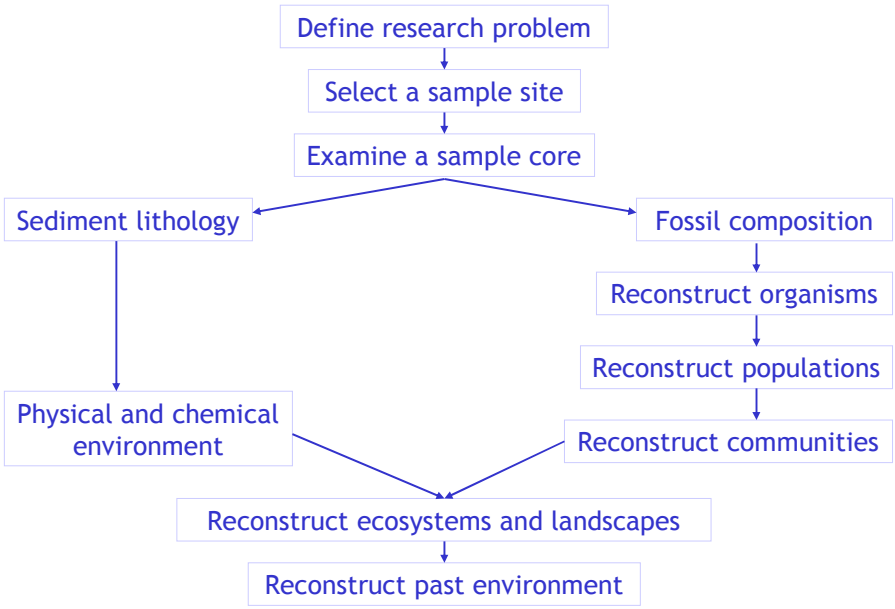
**Archibald Geikie** (1835-1924) Scottish geologist

Coined the phrase

**"The present is the key to the past"**

Important to distinguish between substantive uniformitarianism (**rates** of processes are invariant) and methodological uniformitarianism (**processes** are invariant).

## Stages in a Palaeoecological Study




## Important chronological terms

Quaternary – last 2.7 million years

Holocene - 'post-glacial', last 11,700 cal years

Late-glacial - transition between last glacial stage (Weichselian) and Holocene

consists of

- Younger Dryas/Holocene boundary (YD/H) 11,700 cal yr BP

- Younger Dryas stadial cold phase 12,700-11,700 cal yr BP

- Allerød-Bølling interstadial temperate phase 15,000-12,700 cal yr BP

## Important chronological terms

Last Glacial Maximum (LGM) – about 26,000-19,000 cal yrs BP

Interglacial - previous temperate phases comparable in duration and climate warmth as Holocene

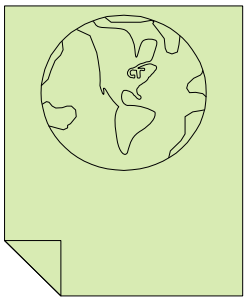
BP - before present ('present' typically AD 1950, occasionally AD 2000)

cal - calibrated years, not radiocarbon years

## How do we do a Q-Time Palaeoecological Study?

1. Set the question – aim of the work

2. Choose site(s)

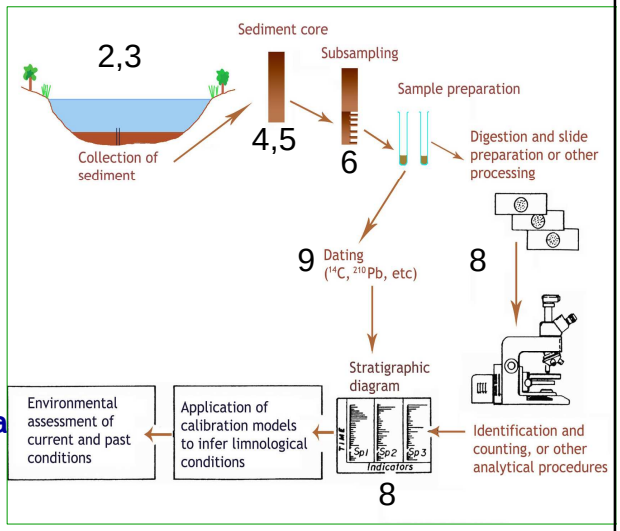


3. Obtain sediment cores

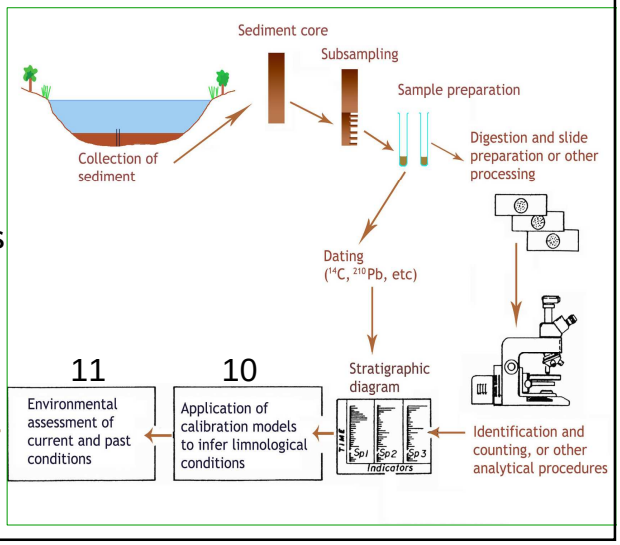
Lake coring from open water

4. Describe the sediments
5. Choose proxies to be analysed
6. Subsample sediments appropriately and prepare them for analyses
7. Do % loss-on-ignition (%LOI)
8. Analyse the proxies and make diagrams (e.g. pollen diagram)
9. Date samples as appropriate ($^{210}$Pb, $^{14}$C)

**Now we have the data**



10. Synthesise and interpret the results in relation to the research question
11. Draw inferences and conclusions
12. Relate to other studies in a wider context
13. Publish the results




## Major types of palaeoecological fossil evidence (proxies) in Q-Time studies

**Biological proxies**

Pollen grains
Macrofossils
Chironomids
Diatoms
Trichoptera
Oribatid mites
Beetles (Coleoptera)
Cladocera

**Physical proxies**

Sediment properties
%loss-on-ignition (LOI)
Geochemistry
Palaeomagnetism
Isotopes

**Dating**

Radiocarbon dating ($^{14}C$-dating)

also vertebrates, molluscs, fungal remains, biochemical markers, ancient DNA

## Proxies most relevant to this lecture are

- Pollen grains and spores of vascular plants
- Macrofossils (seeds, fruits, leaves, etc.) of vascular plants and mosses

Provide evidence of past occurrences, past populations, past communities, past ecosystems and landscapes, and past environments. **Biotic proxies and responses**

- Chironomid head-capsules (non-biting midges)

Provide good 'proxy' for past summer temperature. **Environmental predictor**

Biological proxies important for

biogeography, particularly **historical biogeography**(2)

**palaeoecology**(3)

palaeoclimatology

long-term ecology and conservation biology

**population, community, landscape, and ecosystem ecology**(3,4)

**climate-change biology**(3,4)

**evolutionary biology**(5)

(Numbers refer to lectures in this course where Q-Time palaeoecology contributes to these subjects)

## Quaternary Pollen Analysis

Began in early 20th century. Swedish geologist Lennart von Post had idea of representing results of pollen analysis as stratigraphical diagrams. Demonstrated similarities in pollen diagrams from small areas and differences between areas.

Provides 'vegetation's fourth dimension'.

Dominant technique in Quaternary palaeoecology. Pollen of flowering plants and conifers and spores of ferns are most abundant fossils in organic sediments. Pollen analysis is basis of much Quaternary palaeoecology.

Pollen grains are plant parts found in angiosperms and gymnosperms. Contain male nucleus for fertilization with female nucleus in ovule. Spores are equivalent parts of ferns and fern allies and mosses and liverworts, although the reproductive process is somewhat different.

Wind-dispersed pollen - anemophilous

Insect-dispersed pollen - entomophilous

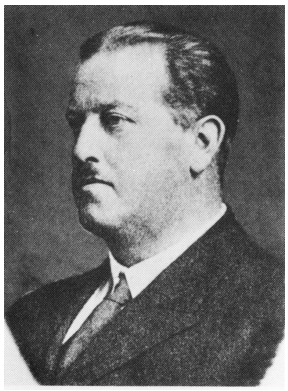
## Basic Principles of Pollen Analysis

1. Pollen and spores produced in great abundance by plants.
2. A very small fraction fulfils natural function of fertilisation. Majority fall to ground.
3. Pollen will decay unless processes of biological decay are inhibited, i.e. in places poor in oxygen (lake bottoms, oceans, bogs) ANOXIC environments.
4. Pollen in atmosphere is well mixed (Pollen rain). Pollen is related numerically to vegetation.
5. A sample of pollen rain is index of vegetation at that time and space.
6. Pollen identifiable to various taxonomic levels.
7. If we examine a sample of pollen rain preserved in lake sediment, get an idea of past vegetation at that time and that space.
8. If do this for several depths, get a record of past pollen rain with time and hence of past vegetation.
9. If we study several sites, can study variation in pollen rain and hence vegetation in time and space.

**Pollen Analysis**

Sweden's Lennart von Post (1884-1950) presented in 1916 the technique of pollen analysis at the 16th Scandinavian meeting of natural scientists in Kristiana (now Oslo).

Proposed that in contrast to large tree remains in peat, pollen could give a ***continuous*** record of vegetational change. He showed strong within-regional similarities in pollen stratigraphy and strong between-regional differences and proposed that there is 'regional parallelism'.

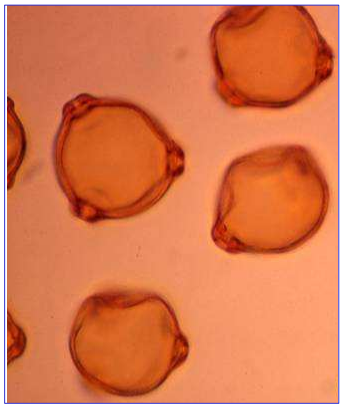


von Post 1916

## Stages in a pollen-analytical study

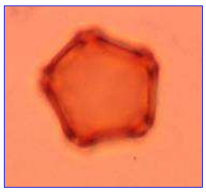
1. Sample sediment core at regular intervals (e.g. every 4 cm) with a volume of 0.5 cc of sediment
2. Treat with series of chemicals to remove humic content, mineral matter, and cellulose and other plant material, and stain pollen grains so that they are more easily visible under a microscope at x400 magnification
3. Identify different pollen types by comparison of fossil grains with modern reference material prepared in same way as fossils

## Pollen grains (10)30-40(100) µm - trees



Betula

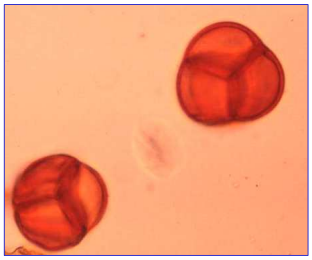
Corylus



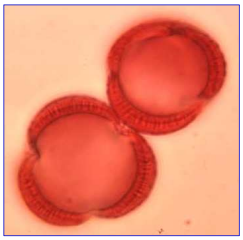
Alnus


Pinus

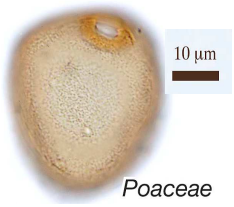
## Pollen grains – shrubs and herbs



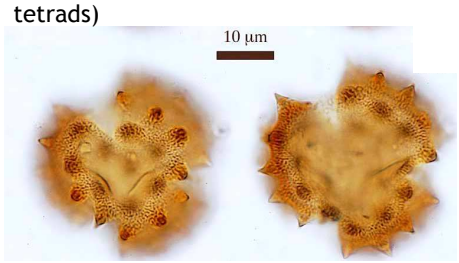
*Empetrum* (Ericaceae; tetrads)



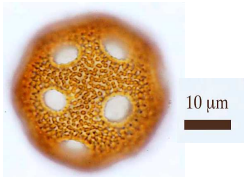
*Artemisia* (Asteraceae)




Poaceae

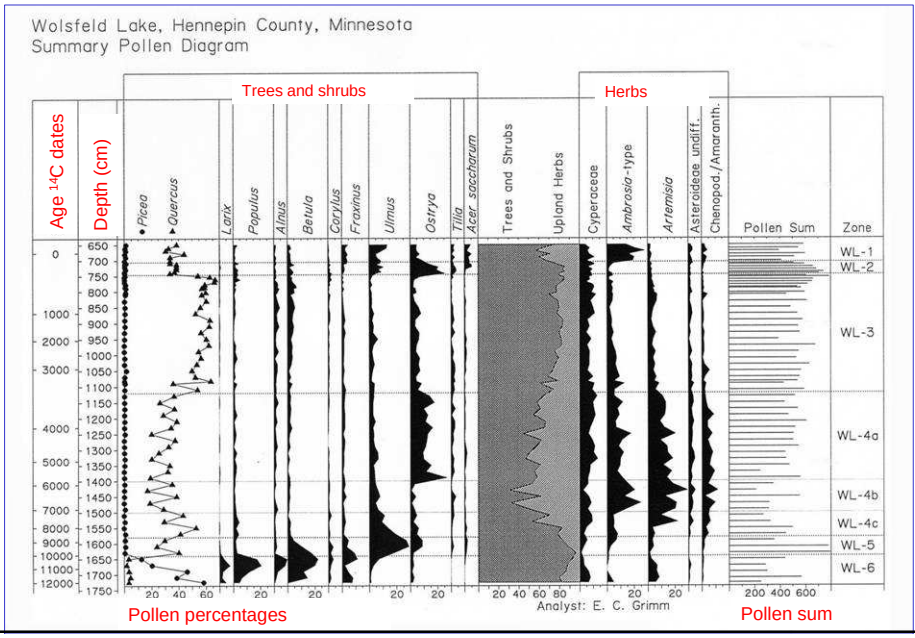



Asteraceae – Tubiflorae (e.g. *Senecio*)




Caryophyllaceae

4. Present data as percentages of total terrestrial pollen and spores as a stratigraphical pollen diagram




5. Interpretation

Pollen originates from flowering plants and gymnosperms

Transported by wind, insects, other animals, water

Related to the vegetation at different scales

Scale is **regional** for abundantly produced and well-dispersed pollen (regional pollen rain)

Scale is **more local** for less-well dispersed pollen

Reflects vegetation changes through time, shown in a pollen diagram

Pollen assemblages from a lake of about 500-750 m diameter reflects the distance weighted abundance of plants in about a 1 km radius of the lake

Predominantly a **regional landscape** record

5. Interpretation (continued)

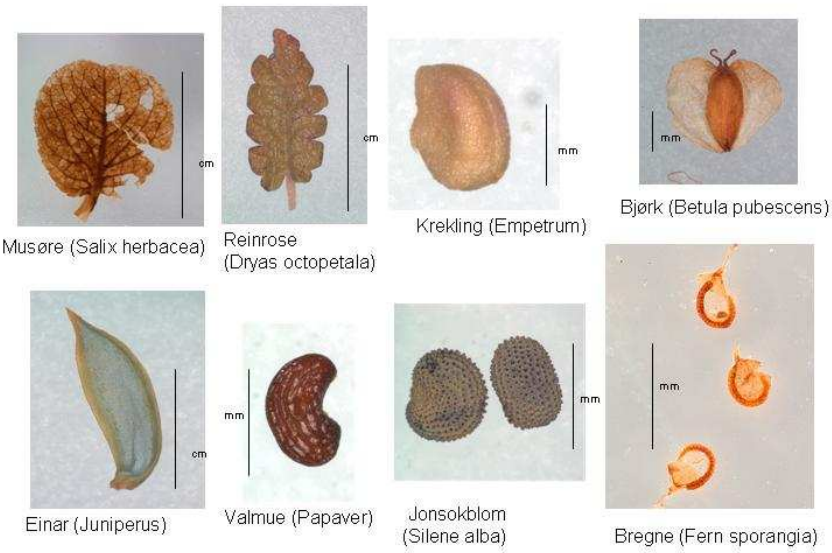
   Can be in terms of past flora, past populations, past communities, past ecosystems, past landscapes, or past environment

   Depends on the original research questions

   See examples of different types of interpretation in this lecture and in the later lectures

## Quaternary Plant-Macrofossil Analysis

Macrofossils – leaves, fruits, seeds, sporangia



Methodology – simple

Wash out known volume (25-50 $cm^3$) of sediment through 125 µm sieve. Transfer residue to storage bottle. Keep cool.

Suspend residue in 2-3 mm water in small dish and examine systematically under a stereo microscope. Identify fossils by comparison with modern reference material.

Parts larger than 0.5 mm (very large tree-trunks to very small seeds)

Derived from all parts of plants. Most often identified are seeds, fruits, and leaves

Usually they are **locally derived**

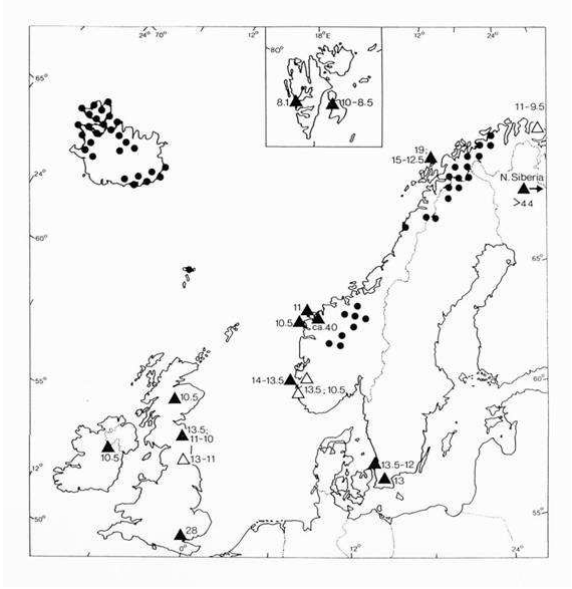
Reflect: species that are present (**good identification**)
local vegetation, both **aquatic** and **terrestrial**

## Comparison of pollen and macrofossils

| | Pollen | Macrofossils |
|---|---|---|
| Concentration (No. $ml^{-1}$) | X $10^5$ | X $10^0$ |
| Spatial resolution | Low, mostly regional source | High, local source |
| Taxon resolution | Genus or family, rarely species | Usually species |
| Usefulness | Regional vegetation | Local flora and vegetation |
| Factors affecting abundance | Production, vegetation cover, preservation, transport ability | Preservation, proximity to coring site, basin characters |

Macrofossils provide **good evidence** for local presence of species, often not possible from pollen alone

*Papaver radicatum*




*Papaver radicatum* agg. ● = modern distribution, ▲ = macrofossil finds (ages x $10^3$ years)

Also provides important evidence of **first occurrence** of taxa, **species identities**, and **assemblage composition** and hence past vegetation.

**Problems** –

- not all sites are 'good' for macrofossils whereas almost all sites have reliable pollen records
- not many skilled plant macrofossil analysts world-wide
- need good botanical knowledge and extensive modern reference collections

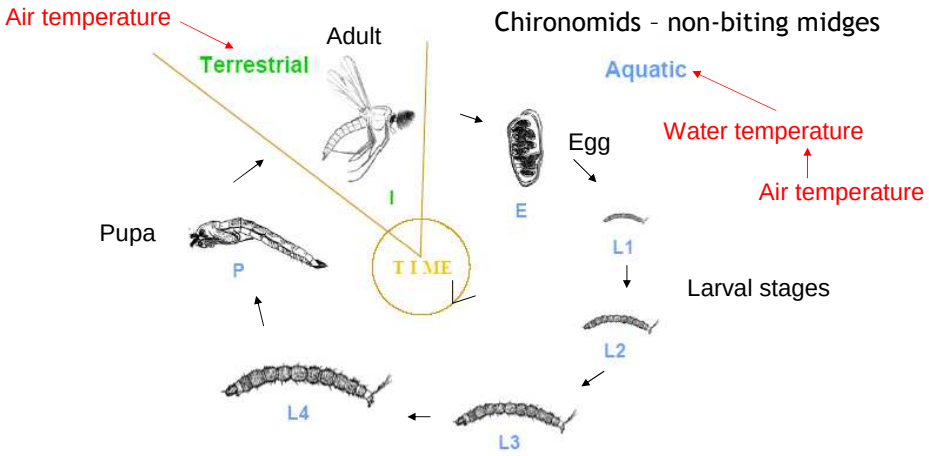
Macrofossils provide 'The Factual Basis for Phytogeography' (Godwin 1956)

Pollen and macrofossils provide evidence for past flora, vegetation, and landscapes. Most useful when used together

What about the past environment?

## Quaternary Chironomid Analysis

Recent development in Q-Time palaeoecology in the last 20 years. Use of chironomid remains as an **environmental proxy** independent of botanical proxies



## Chironomid larva

Chitinised head capsule

## Fossil chironomid head capsules

*Chaetocladius piger*

Feed on algae;
Need oxygenated water,
Cool oligotrophic lakes
Good indicators

*Tanytarsus gracilentis*

Need oxygenated water,
Cool oxygenated lakes,
Good indicators

## Chironomids

Ecology: Larvae are aquatic. Adults can fly – so respond fast to changing conditions

Respond to:

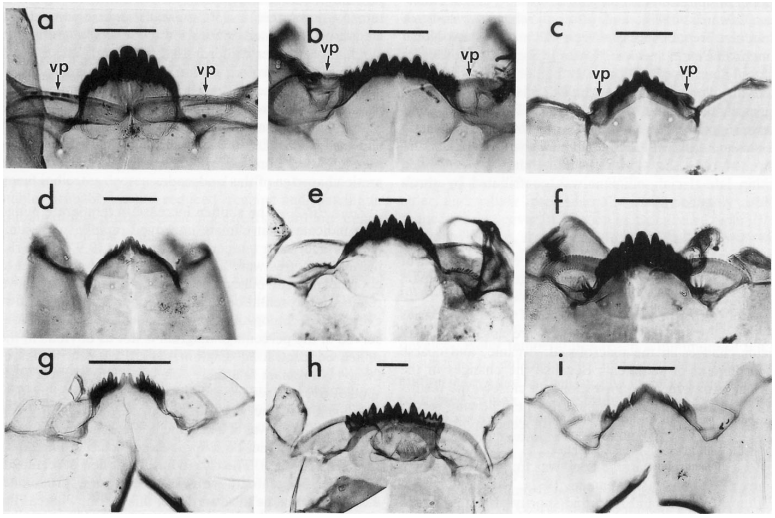
Larvae – **water temperature**, oxygen availability, nutrient and base status

Adults – **air temperature** in summer. Air temperature is a major factor affecting water temperature

Eat: detritus, plankton, some are carnivorous

Used: to reconstruct **mean July air temperature** using **transfer functions**. Also nutrient and oxygen conditions

## Chironomids - good indicators of past lake-water temperatures and hence past climate




Common late-glacial chironomid taxa. A: *Tanytarsina*; b: *Sergentia*; c: *Heterotrissocladius*; d: *Hydrobaenus/Oliveridia*; e: *Chironomus*; f: *Dicrotendipes*; g: *Microtendipes*; h: *Polypedilum*; i: *Cladopelma*. Scale bar represents 50 μm.

## Basic idea of quantitative environmental reconstruction

Fossil biological data
(e.g. pollen, chironomids)
'Proxy data'

1, ..... m species
|
$Y_0$
|
t
samples

Environmental variable
(e.g. temperature)

1
|
$X_0$ Unknown.
To be estimated
or reconstructed
|
t
samples

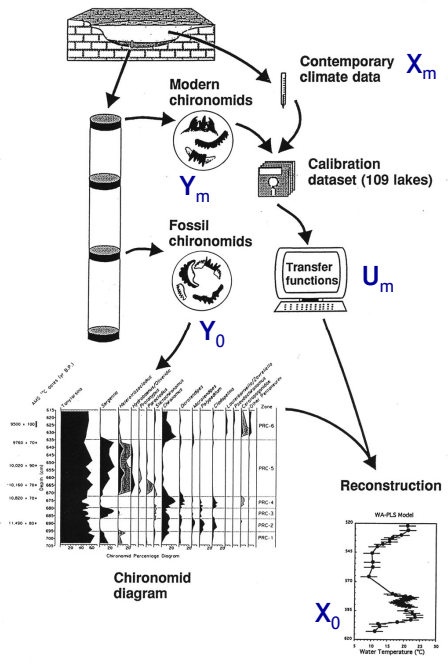
To solve for $X_0$, need modern data or 'training data' or 'calibration set'

1, ..... m species
|
$Y_m$
|
n
samples

Modern biology
(e.g. pollen, chironomids)

1
|
$X_m$
|
n
samples

Modern environment
(e.g. temperature)



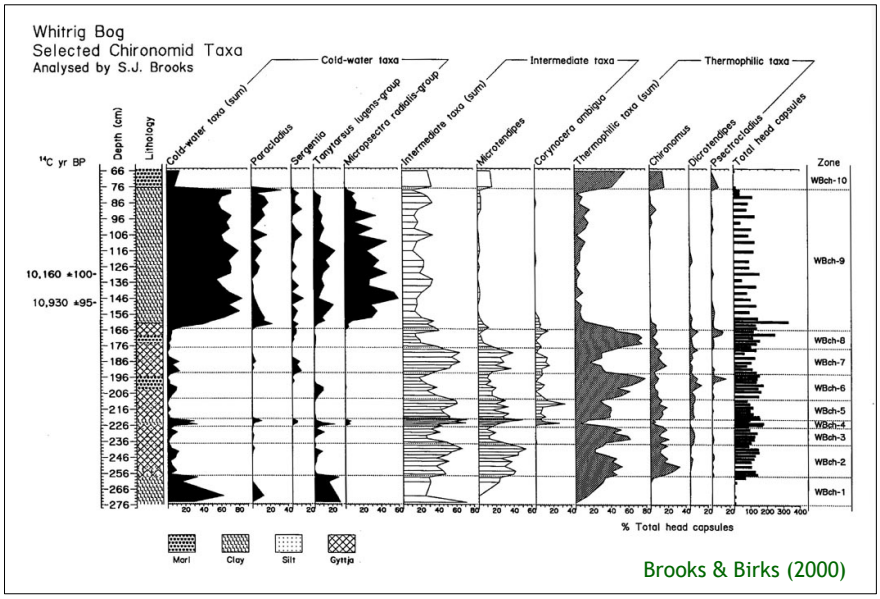

modern biology
transfer function
modern environment

$$Y_m = U_m X_m$$

$$X_0 = U_m^{-1} Y_0$$

past environment
fossil assemblage
inverse of transfer function

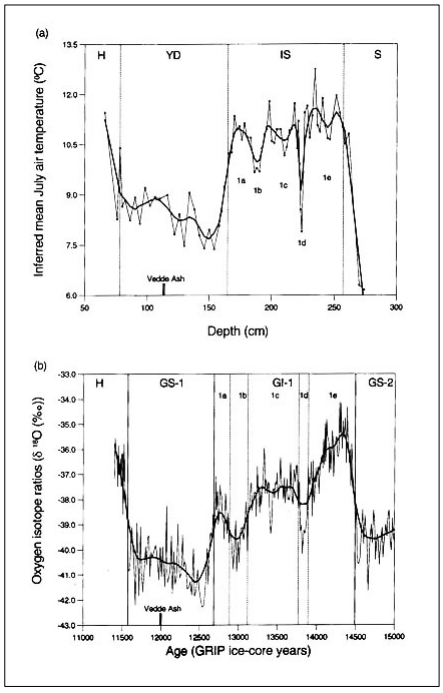
## Late-glacial chironomid temperature reconstructions




Brooks & Birks (2000)

Inferred mean July air temperature using modern chironomid-temperature transfer function

Oxygen isotope ratios in Greenland ice-core




Brooks & Birks (2000)

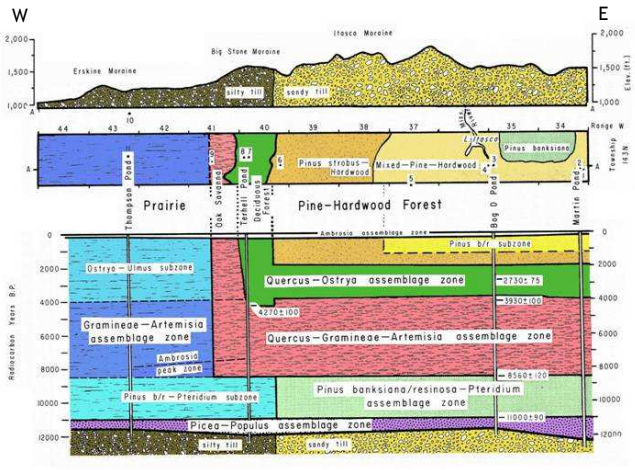
Chironomid mean July air temperature reconstructions based on 157-lake modern 'training-set' across Norway and Svalbard. Prediction error in cross-validation about 1°C.

Use to provide palaeoenvironmental reconstruction, in this case, mean July air temperature, that is **independent** of botanical proxies.

Thus we have plant 'responses' and environmental 'predictor'. Can now look at long-term biotic responses.

## Some Examples of Q-Time Palaeoecological Studies

1. **Reconstruction of past vegetation in NW Minnesota using pollen analysis**



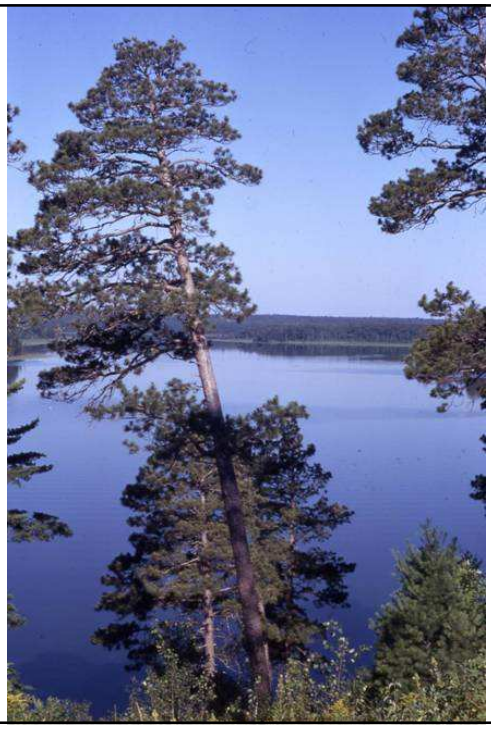

Itasca transect: landforms, vegetation, and chronosequence of pollen assemblage zones. The transect is 66 miles long and 6 miles wide. The numbers are ponds from which short cores were taken.

JH McAndrews

Lake Itasca

Pine-hardwood forest

*Pinus strobus, Betula papyrifera, Populus tremuloides*



Bear Paw Point

Deciduous forest

*Tilia, Acer, Ulmus, Quercus*

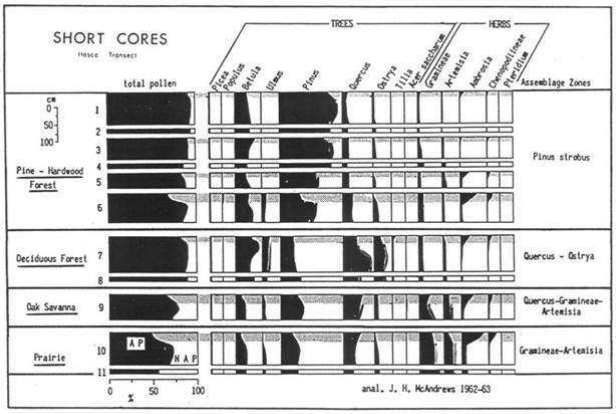
Alison's Savannah – *Quercus macrocarpa* savannah

Frenchman's Bluff – Prairie
Short-grass *Artimisia* prairie

Bog D – Pine-hardwood forest

Terhell Pond – Deciduous forest

Thompson Pond - Prairie




Summary pollen diagrams from the upper metre of sediments in the seven short-core sites, together with an average spectrum for each of the four long-core sites from levels just below the settlement horizon. Vegetational formations are named at the left. AP = arboreal pollen; NAP = non-arboreal pollen.

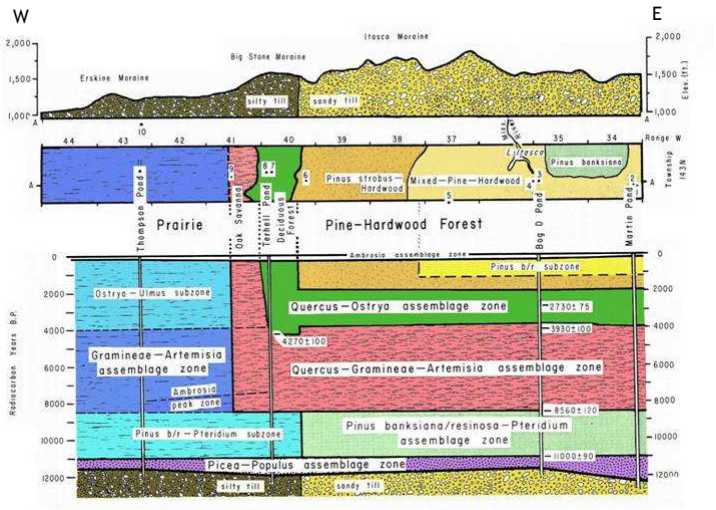
Summary pollen assemblages prior to European settlement for vegetation types in N.W. Minnesota (from McAndrews 1966, 1967)

| Vegetation type | *Gramineae* | *Artemisia* | *Quercus* | *Ulmus* | *Pinus* | *Ostrya* |
|---|---|---|---|---|---|---|
| Pine-hardwood forest | <5% | <5% | <10% | <5% | >35% | <5% |
| Mixed deciduous forest | <10% | <5% | 15-30% | 10% | <30% | >10% |
| Oak savannah | 10-50% | 5-20% | >10% | <5% | <20% | <5% |
| Prairie | 10-50% | 5-20% | <10% | <5% | <20% | <5% |

Expressed as percentages of total pollen excluding Cyperaceae and obligate aquatic taxa

Compare fossil assemblages with these as basis for interpretation in terms of past vegetation

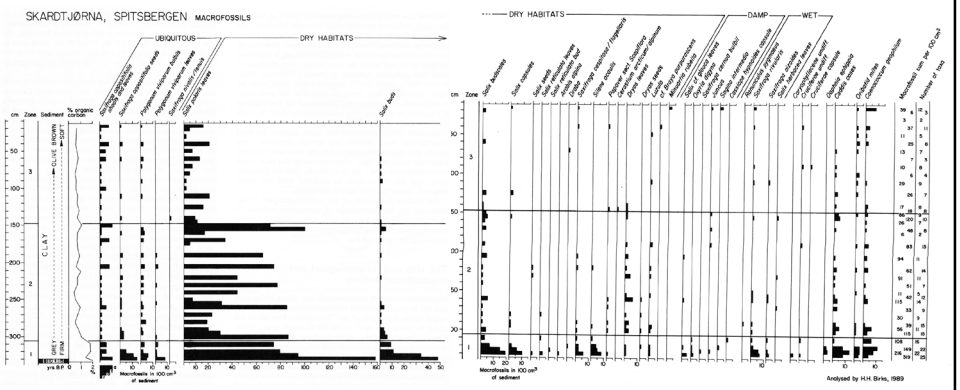
## Time-space diagram along Itasca transect




Itasca transect: landforms, vegetation, and chronosequence of pollen assemblage zones. The transect is 66 miles long and 6 miles wide. The numbers are ponds from which short cores were taken.

JH McAndrews

## 2. Reconstruction of long-term vegetation and landscape changes in high Arctic



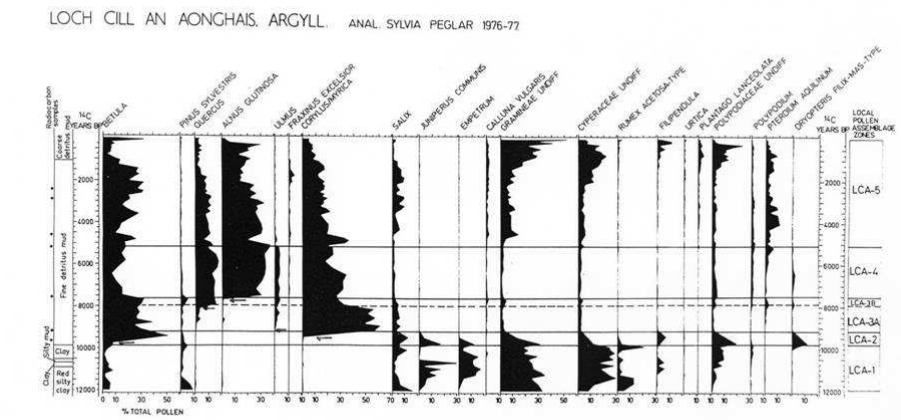

**Macrofossil** concentration diagram from Skardtjørna, Spitsbergen. Values are numbers in 100 $cm^3$ sediment. Pollen of almost no value – very low local pollen production. Macrofossils essential

'Polar Desert', Outer Fjord, western Svalbard - today

Middle-arctic, Inner Fjord, western Svalbard – as it may have been in 'Mid-Holocene Thermal Maximum' about 5000 yrs ago

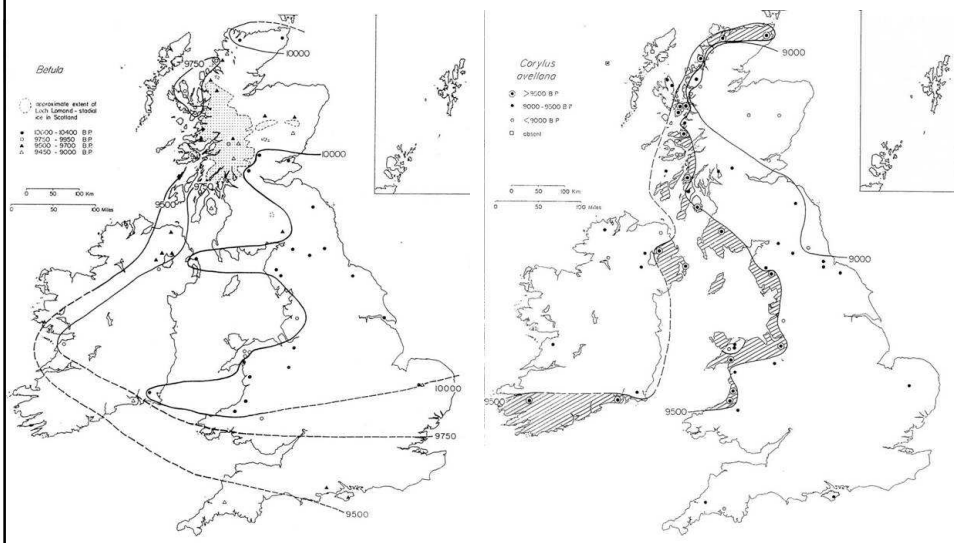
## 3. Reconstruction of long-term tree dynamics at a landscape scale in British Isles

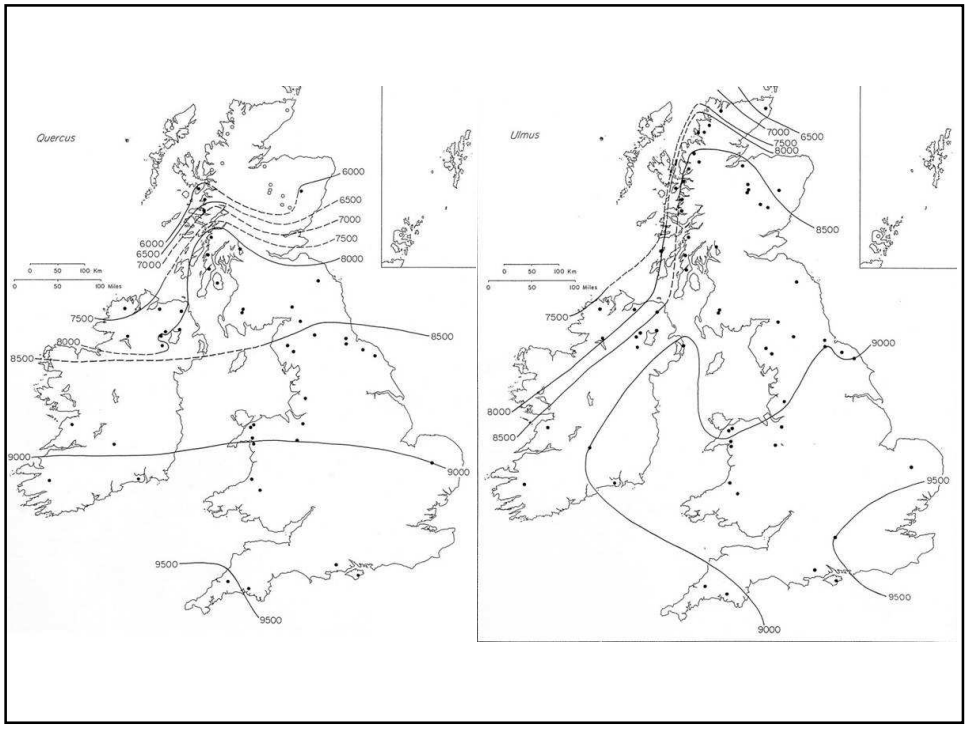

Birks (1989)

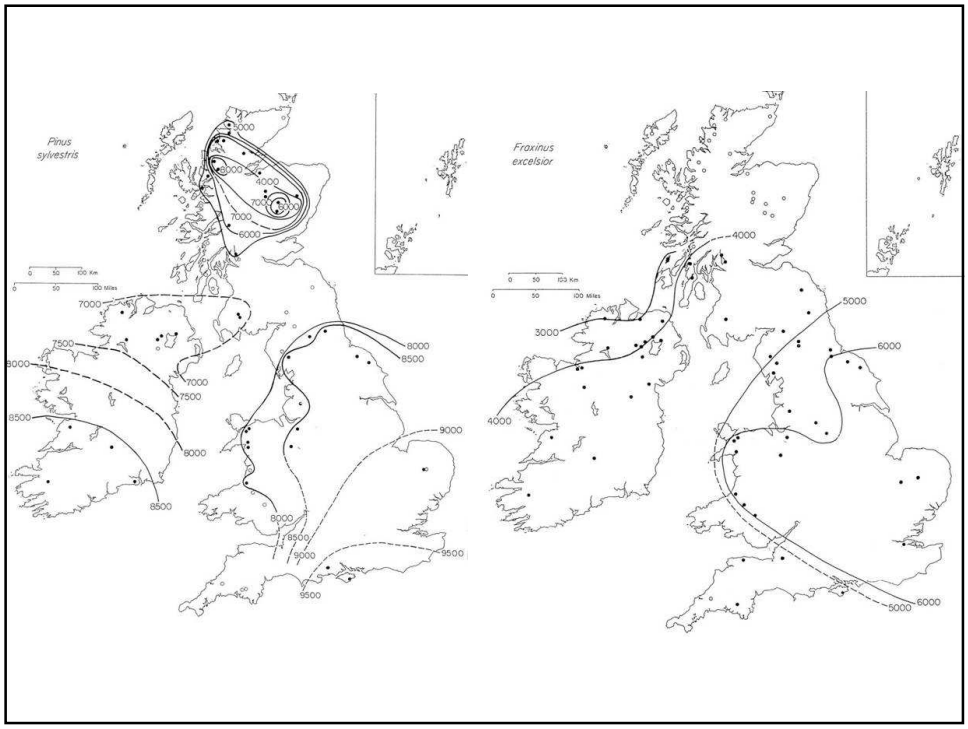


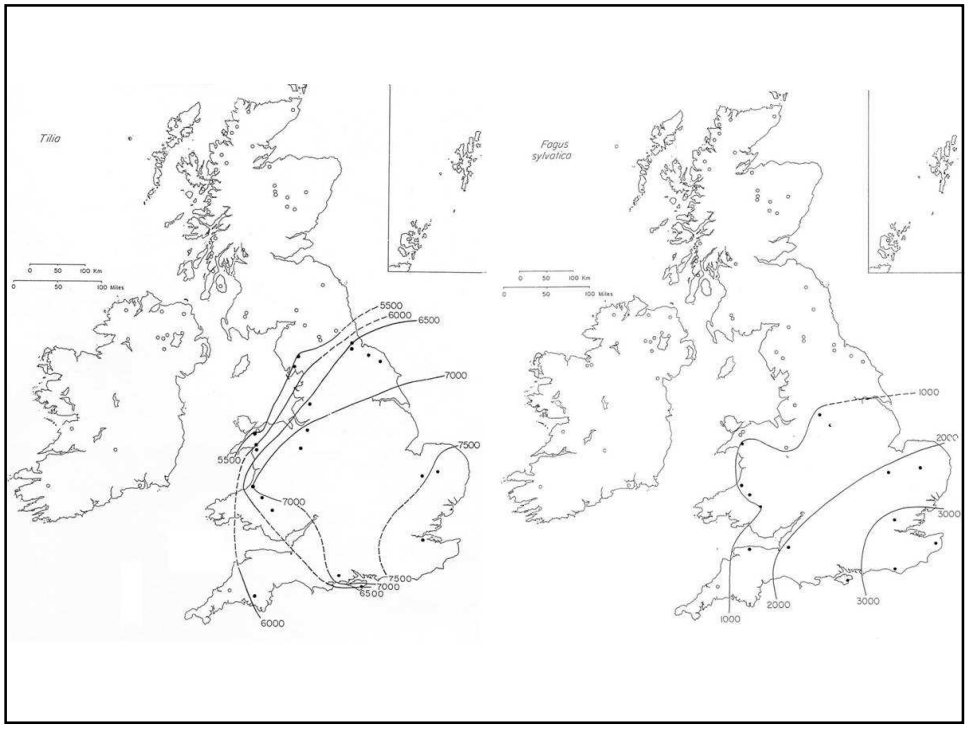

Define first expansion of major trees

Isochrones – times of first expansion in radiocarbon yrs BP

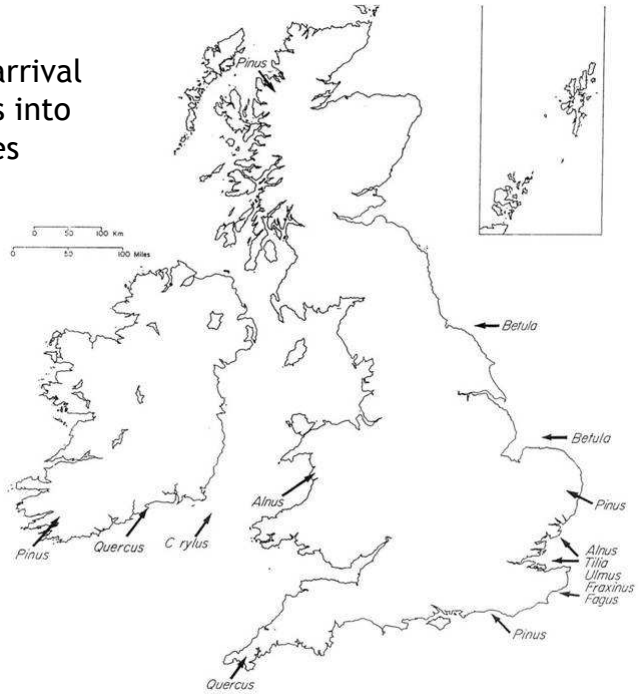



Quercus
6000
6500
7000
7500
8000
8500
9000
9500
Ulmus
7000
6500
7500
8000
8500
7500
9000
8000
8500
9500
9500
9000


Pinus sylvestris
7000
6000
7000
7500
8000
8500
7000
7500
8000
8500
9000
8000
8500
9000
9500
9500
Fraxinus excelsior
4000
3000
5000
6000
4000
5000
6000

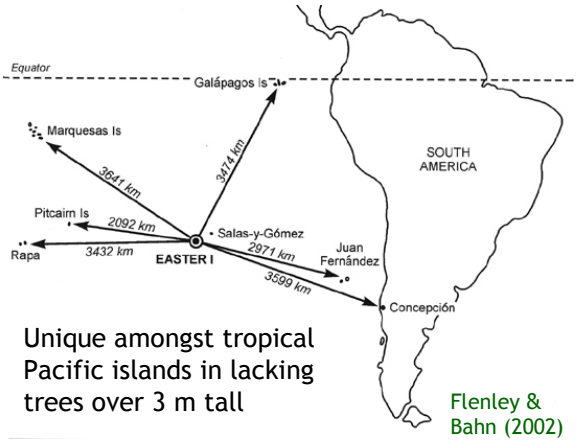



Approximate directions of arrival of forest trees into the British Isles



## 4. Reconstruction of ecosystem and landscape on Easter Island - Q-Time palaeoecology and Real-Time ecology meet

Easter Island, a remote volcanic island in the Pacific Ocean. Famous for Thor Heyerdahl's Kon-Tiki expedition and its huge, stone statues or *moai* (about 800-1000 in number).



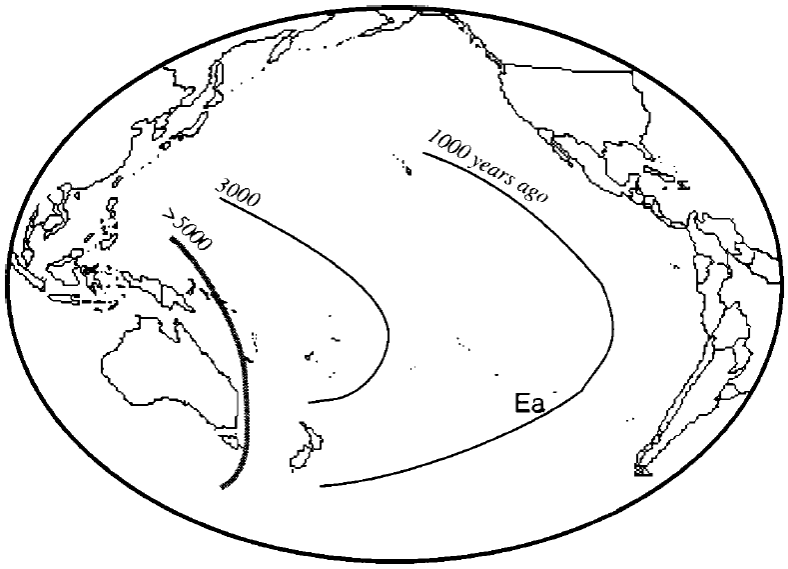

Unique amongst tropical Pacific islands in lacking trees over 3 m tall

Flenley & Bahn (2002)

Rano Kau crater

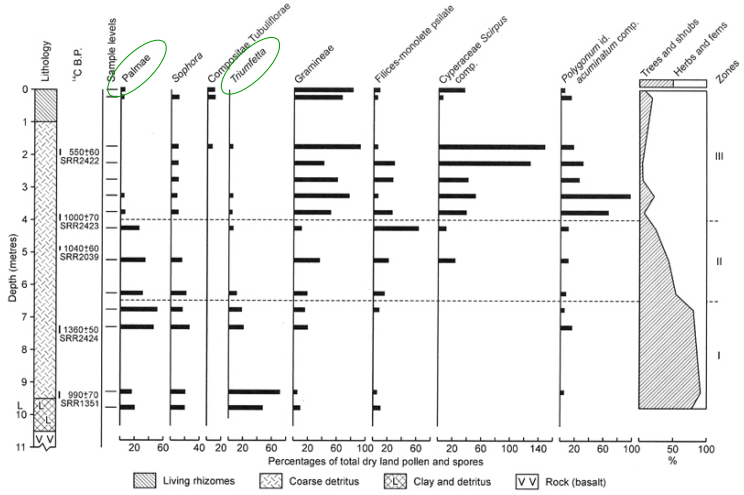
Moai on outer slopes of Rano Raraku crater

Flenley & Bahn (2002)




Colonised by Polynesians about 1700 (~300 AD) years ago

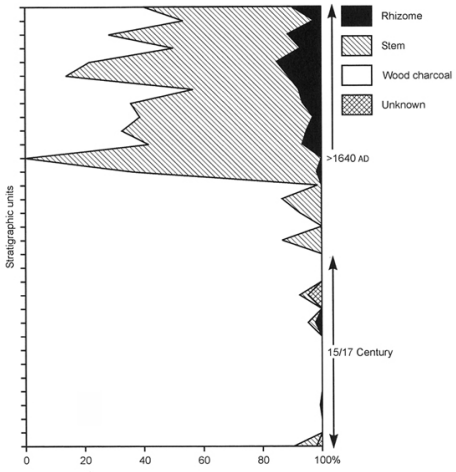
Pollen diagram from Rano Kau crater




Triumfetta (hauhau), a tree used for rope - extinct on Easter Island
Palmae (palms) – extinct on Easter Island
Major change about 1000 years ago

Flenley & Bahn (2002)

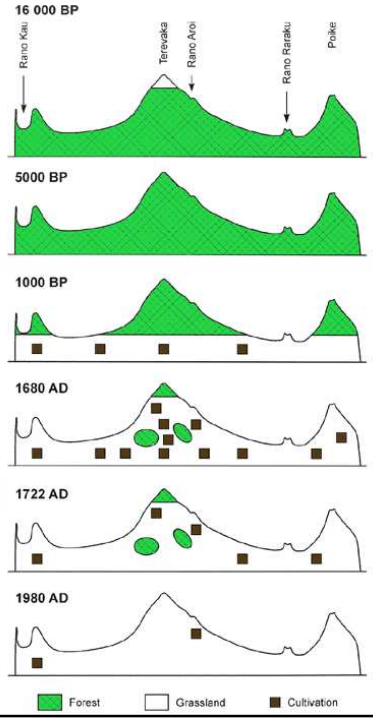
## Charcoal stratigraphy




Major changes about 800 years ago. Change from wood charcoal to grass stems and rhizomes.

Flenley & Bahn (2002)

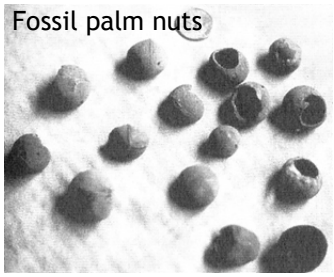
## Reconstructed vegetation

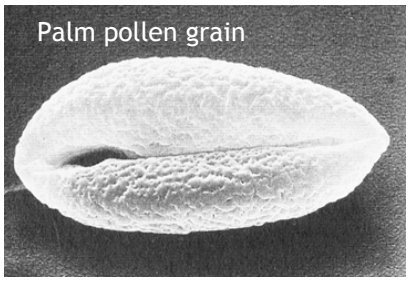



Flenley & Bahn (2002)

What was the dominant tree? No trees on Easter Island today.

Found fossil palm nuts in cave and also palm root moulds.



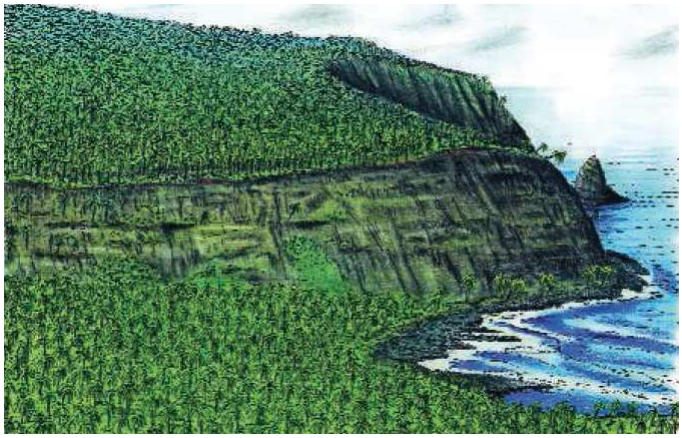




Flenley & Bahn (2002)

Palm root moulds

Totally extinct species of palm. Closest to *Jubaea chilensis*, the Chilean wine palm of western Chile but the nuts on Easter Island are NOT *J. chilensis*. **Extinct species**.

Hunt (2007)



Artist's impression of Poike Peninsula, Easter Island prior to human arrival. Covered by *Jubaea* palm.

Diamond (2007)

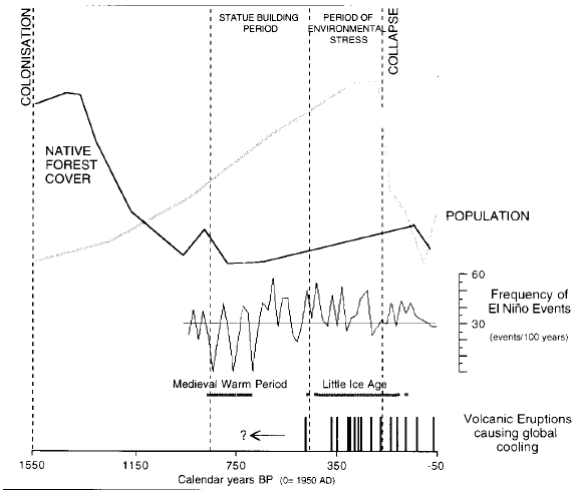
Charcoal remains from ovens and middens show 20 other tree and woody plants exterminated during human settlement.

- Palm gone by AD 1450, other trees by AD 1650.
- Islanders then burnt grasses and sedges for fuel.
- Loss of trees meant loss of fibres, bark, wood, etc.
- Major change in agricultural practices.
- Major soil erosion, low crop yields by AD 1400.
- AD 1400 – starting of 'stone mulching' – covered 50% of island with stones averaging 2 kg in weight:
  - reduces evaporation
  - protects against erosion,
  - reduces temperature fluctuations, and
  - may fertilize soils.
- Soils very low in P. Islanders had exterminated sea-birds and hence their guano.

Islands once forested, deforested by Polynesian settlers. Oldest radiocarbon date for human occupation is 386 ± 100 AD, about 1700 years ago. Youngest is 1770 ± 60 AD.

1772 AD ‘islands destitute of trees’

1774 AD Captain Cook – many statues overturned, evidence for human fighting, rapid death, and cannibalism. Suggestive of great food shortage and societal collapse.

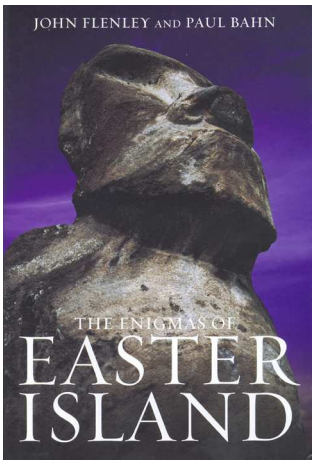


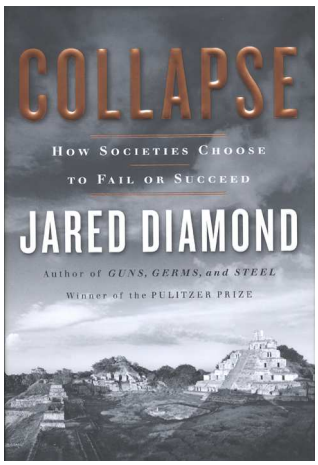

Likely scenario: forested island, forest destruction, statue building period, environmental stress, and population collapse

Role of climate in societal collapse possible. Statue building at time of low frequency of El Niño events (few droughts). Stress and collapse at time of intense El Niño events (many droughts) and frequent volcanic disruption of global climate (low temperatures).

Shows (1) global extinction of an endemic palm as a direct result of human activity (Sixth Extinction Event)

(2) possible interaction between climate and societal changes leading to societal collapse




Jared Diamond 'Collapse' uses Easter Island as a paradigm for coming centuries of Earth's history

In contrast to Easter Island where extinction of the endemic palm occurred, palms do not appear to have gone extinct on other oceanic islands of the Pacific Ocean.

Severe reduction of faunal diversity of islands such as Fiji, French Polynesia, Hawaiian Islands, Juan Fernandez Islands, Cook Islands, and Easter Island with human colonisation.

Strong correspondence between human impact and palm decline:

*Pritchardia*
Decline: 2/17 Local extinction (extirpation): 15/17
Other Palms
Decline: 8/14 Local extinction: 3/14
Local or total extinction: 2/14 Extinction: 1/14

Overall pattern is decline or local extinction and only **one total extinction** on Easter Island and **two possible extinctions** on Norfolk Island (Australia) and Vita Levu (Fiji).

See Prebble & Dowe (2008) Quat Sci Rev 27: 2546-2567

Easter Island perhaps unique.

## Additional features about Easter Island's ecological catastrophe

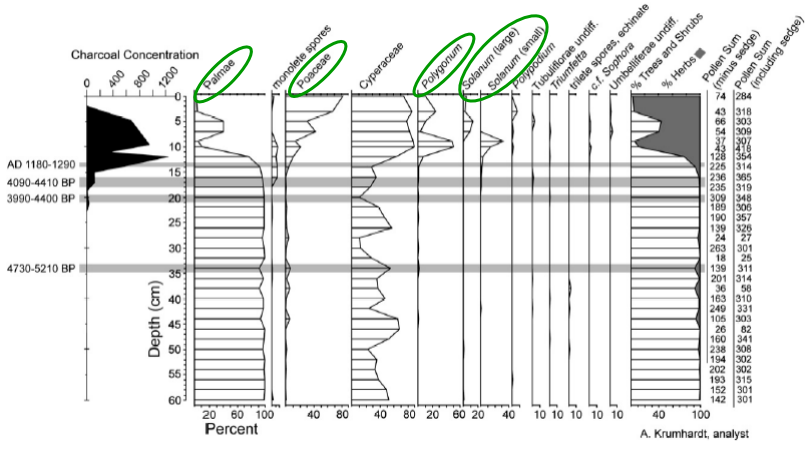
i. Accidental or deliberate introduction of rats (*Rattus exulanus*). Likely density 45 rats per acre, or 1.9 million rats.

Rat-gnawed *Jubaea* palm nuts

Rats would have eaten and damaged nuts and seedlings and prevented regeneration

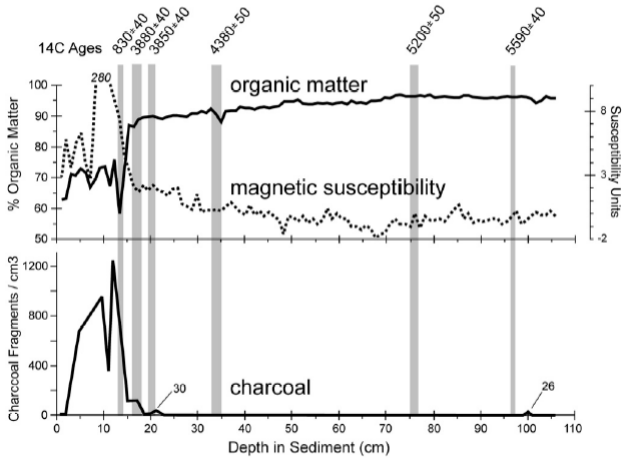
Hunt (2007)

ii. Human colonisation of Easter Island well established by AD 1200, followed by rapid deforestation




Decline of Palmae (palm trees). Rise of Poaceae (grasses), *Solanum*, and *Polygonum*. Gaps in sediment sequence due to droughts.

Mann *et al*. (2008)



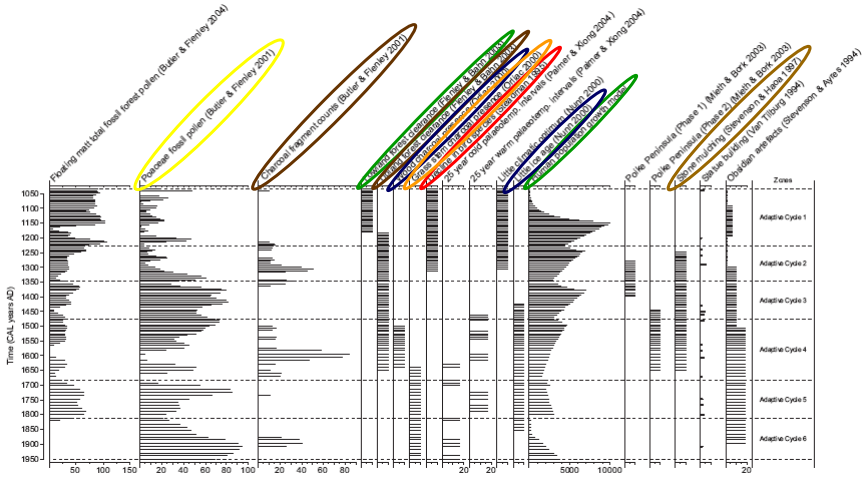

Mann *et al.* (2008)

830 $^{14}$C yrs = AD 1180-1290

rise of charcoal, magnetic susceptibility

decrease of % organic matter (= increase of % mineral matter) with deforestation

## iii. Very fine-resolution studies and human-population growth models




1050 (top) to 1950 (bottom) AD – wrong way up!

Suggests six adaptive cycles

Cole & Flenley (2008)

iv. 900 statues on Easter Island. Most from 19 quarries in Rano Raraku crater. Different size and style of statues on two sides of island

By AD 1600, wood very scarce. Started to build stone buildings. Used caves and built stone walls to block entrances.

Major changes before European arrival.

v. Mysteries of Easter Island – Diamond 2007

- Had its own rongorongo writing. How old is it? Was it the world's smallest community to invent writing independently?
- Did the Easter Islanders live in isolation until European arrival? Does the rise of *Solanum* pollen at about AD 1500 signify the arrival of sweet potato?
- When did the first settlers arrive between AD 800 and AD 1200?
- How did the population rise and fall and when did it peak?
- Were the 19 quarries for statue carving owned by different clans?
- How old are the statues? Oral tradition says the last one was carved in AD 1680.

## 5. Examples of studying the ecology of the past

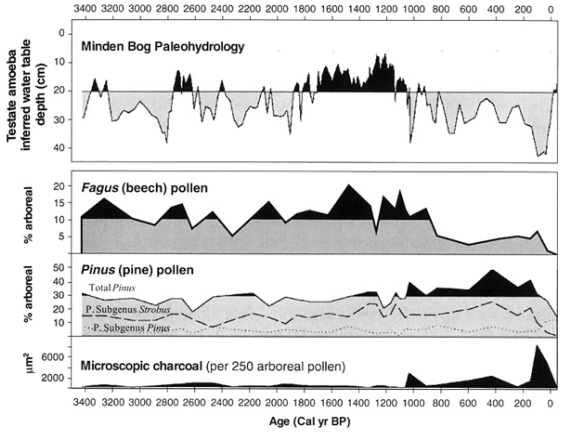
Two approaches:

1. Study **responses of organisms** in the past to environmental changes but the environmental record is **not** based on the fossils but is based on **independent palaeoenvironmental records** (e.g. stable isotopes, testate amoebae).

2. Multi-proxy studies in which we use **one biological** proxy as the basis for the **environmental reconstruction** (e.g. plant macrofossils, chironomids) and the other biological proxy as a response variable.

Both give an environmental record that is **independent** of one or more groups of fossils of interest.

## Multi-proxy studies and two biological proxies; one a response, other a predictor



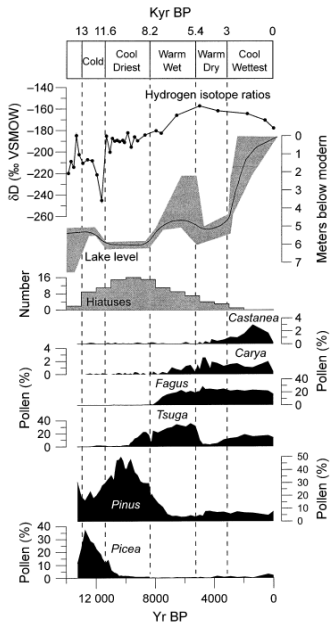

Minden Bog, Michigan.
Booth & Jackson (2003)

Black portions = wet periods,
grey = dry periods

Major change 1000 years ago towards drier conditions, decline in *Fagus* and rise in *Pinus* in charcoal

Climate → vegetation → fire frequency

## Multi-proxy studies of biological and physical proxies




Central New England, eastern USA

Environmental proxies

- hydrogen isotope ratios as temperature proxy (low values indicate colder temperatures)
- lake levels indicate moisture balance

See major pollen changes coincide with climatic transitions

Climate control of vegetational composition at millennial scales

Shuman *et al.* (2004)

These new approaches involving environmental reconstructions **independent** of the main fossil record can be used as a long-term ecological observatory or laboratory to study long-term ecological dynamics under a range of environmental conditions, not all of which exist on Earth today (e.g. lowered $CO_2$ concentrations, low human impact).

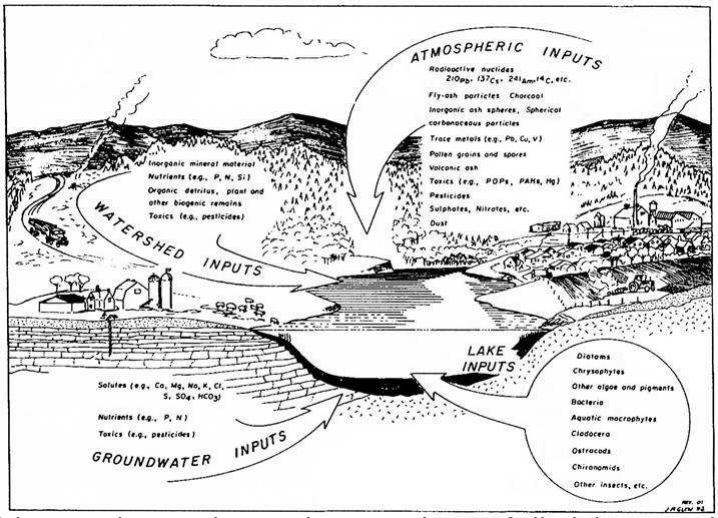
We will use the approach of different biotic proxies to consider plant migration, persistence, and adaptation in response to environmental change in a Q-Time perspective.

## Conclusions

1. Q-Time palaeoecology can be concerned with reconstructions of past flora, populations, vegetation, ecosystems, landscapes, and environments. Primarily a **geological** approach.
2. Q-Time palaeoecology can also be concerned with biotic responses to environmental change, with evolutionary legacies in relation to environmental change, and with ecosystem responses to environmental change, Primarily an **ecological** approach.
3. We primarily adopt the **ecological** approach and consider historical biogeography, biotic responses to rapid environmental change, and evolutionary legacies of the Ice Ages.

4. Important to remember Q-Time palaeoecology is now a vast **multi-disciplinary** subject that is making major contributions to assessing ecosystem health, to providing a long-term perspective for conservation biology and management, to understanding timing and rates of freshwater pollution by nutrients and by acid-rain, and to providing insights into environmental change during the evolution of early hominids.
5. Increasing close links with phylogeography and historical biogeography, with studies involving ancient DNA, and with evolutionary biology.
6. Major advances have come from the discovery of all the proxies preserved in lake sediments.

# The importance of lakes as a long-term ecological observatory




Schematic diagram showing the accumulation of allochthonous and autochthonous indicators used by palaeolimnologists to track long-term environmental change (modified from Charles *et al*. 1994).