Long-Term Ecology and Management in Upland Landscapes – controversies, challenges, and compromises

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DYLAN – Åpningsseminar, Trondheim 23-24 February 2009

What is long-term ecology?
Why study long-term ecology?
Why is long-term ecology largely ignored in nature management and conservation biology?
What are the key advances in long-term ecology?
Can long-term ecology contribute to understanding landscape history?
Can long-term ecology contribute to understanding landscape diversity?
Can long-term ecology contribute to understanding determinants of diversity?
Can lake history contribute to understanding landscape dynamics?
Can long-term ecology contribute to other aspects of management and conservation?
What are the challenges?
What are the compromises?
Conclusions

What is Long-Term Ecology?

Long-term ecology = ecological palaeoecology, namely using palaeoecology to resolve critical questions about long-term ecological change. Concerned **primarily** with the ecological impacts of environmental change on organisms, communities, ecosystems, and landscapes.

Uses the palaeoecological record of fossil pollen, spores, leaves, fruits, seeds, etc in lake and bog sediments as a **long-term ecological laboratory** or observatory.

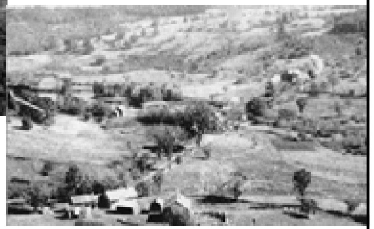
Not primarily concerned with the reconstruction of past environments (e.g. climate) (as in geological palaeoecology) but with the **responses** of organisms in the past to environmental change.

Why Study Long-Term Ecology?

"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

... 120 years ago



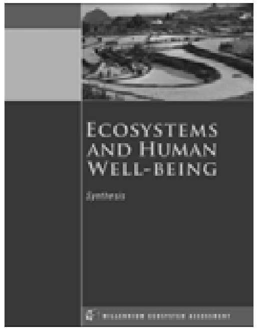
Harvard Forest today

Do landscape management and conservation biology take history into account?

NO!

Millennium Ecosystem Assessment 2005
www.maweb.org

UN commissioned MEA concluded that



- There is little knowledge of how ecosystems respond to the interactive effects of different drivers in particular regions and across different scales
- There is a limited understanding of characteristics of ecosystems that lead to thresholds and irreversible changes
- Such information is critical in order to develop policies and conservation strategies to cope with current and future change
- Longest temporal data set used in MEA is 45 years (1960-2005)

What about other conservation assessments?

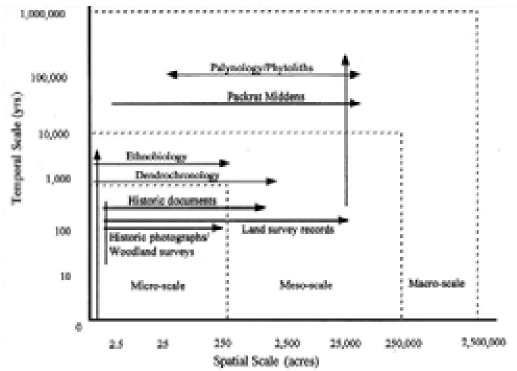
Table 1. Recently published biodiversity assessments and reports

Biodiversity Assessment/report	Commissioning organization	Author/Year/Web address	Longest temporal data set used
Living Planet Report 2002;	WWF	Loh, J. (2002) http://www.wwf.org.uk/filelibrary/pdf/livingplanet2002.pdf	30 years (1972–2002)
Red List of Threatened Species: Global Species Assessment	IUCN	IUCN (2004); http://www.iucnredlist.org	8 years (1996–2004)
Global Environment Outlook (GEO-3)	UNEP	UNEP (2002); http://www.unep.org/geo/geo3/	30 years (1970–2000)
Millennium Ecosystem Assessment	UNDP, UNEP, World Bank and WRI	UNEP (2001); http://www.millenniumassessment.org/en/global.condition.aspx	45 years (1960–2005)
Global Forest Resources Assessment 2000	FAO	FAO (2001); Forest Resource Assessment http://www.fao.org/forestry/site/7949/en	10 years (1990–2000)
World Atlas of Biodiversity	UNEP-WCMC	See [12].	30 years (1970–2000)
Measuring Biodiversity for Conservation	Royal Society, London	Royal Society Working Party (2003); http://www.royalsociety.org/document.asp	52 years (1950–2002)

Willis *et al*. 2005

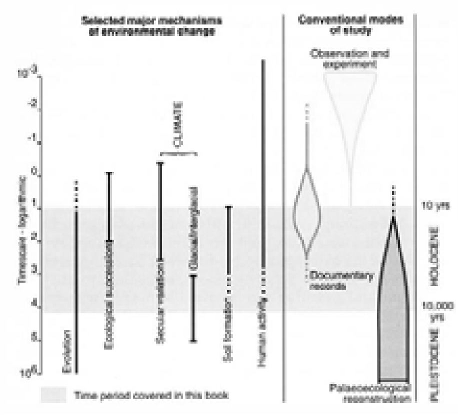
Range is 8-52 years

Spatial and temporal scales of long-term ecological techniques



Egan & Howell 2005

Relationship between long-term ecology and modern ecology



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

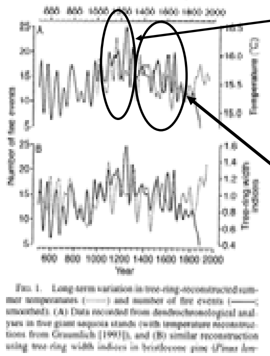
- Both ecological and human systems have substantial inertia, and the impact of changes occurring today may not be seen for years or decades.
- For example, the MEA states that: ‘Some fisheries’ catches may not decrease for several years even after they have reached unsustainable levels because of the ‘large number of juvenile fish produced before that level was reached’
- Some changes occurring in the past we may only be seeing today…

1000 years of forest history in Sierra Nevada, California

Measurement of the age of trees in the forests in eastern Sierra Nevada found 3 age classes

- Old growth firs (300-550 years old)
- Lodgepole pines (250-100 years old)
- Young red firs (<100 years old)

Miller & Woolfendon 1999



Response of vegetation in region to Medieval warm period (900-1350 AD) included:
- Increase in number of fire events
- Increase in abundance of firs in high-elevation communities

Response of vegetation to Little Ice Age (1350-1850 AD):

- Decrease in fire events
- Lodgepole pines became dominant

Following Little Ice Age (1850-present) - firs became established once again

- Current forest is a reflection of the 3 climate changes occurring over past 1000 yrs – Medieval warm period, Little Ice Age, recent warming

Miller & Woolfendon 1999

Why is Long-Term Ecology Largely Ignored in Nature Management and Conservation Biology?

Several possible **controversial** explanations

1. Nature managers' views
   - palaeoecological data too descriptive and too imprecise in terms of spatial, temporal, and taxonomic precision. Data are thus of little or no relevance to real-life conservation management
   - unfamiliar literature, concepts, and methods
   - data presented in complex way, the 'dreaded unreadable long pollen diagram'

2. Palaeoecologists' views
   - vast majority of palaeoecologists interested in time scales of the Holocene (11600 years), the late-glacial, and of detectable human impact
   - do not see the relevance of their data to nature conservation and management
   - tend not to concentrate on the 'recent past' (last 500 years), the period most relevant to conservation
   - often, rather surprisingly, not interested in present-day ecology, conservation, or management

Two cultures, or at least sub-cultures, seemingly interested in landscape dynamics, past, present, and future but not interested in the other sub-cultures

A few exceptions:

POLLEN ANALYSIS AND THE HISTORY OF LAND USE*
Professor F. OLDFIELD *School of Biological and Environmental Studies, New University of Ulster, Coleraine*
Advancement of Science 25, March 1969

Contributions of Quaternary palaeoecology to nature conservation
Birks, H.J.B.

How "Virgin" Is Virgin Rainforest?
16 APRIL 2004 VOL 304 SCIENCE

'As Earth's testimonies tell': wilderness conservation in a changing world
Lindsey Gilbson and Katherine J. Willis
Ecology Letters, (2004) 7: 990-998

What Is Natural? The Need for a Long-Term Perspective in Biodiversity Conservation
K. J. Willis and H. J. B. Birks
SCIENCE VOL 314 24 NOVEMBER 2006

Emerging issues in biodiversity & conservation management: The need for a palaeoecological perspective
C.A. Froyd, K.J. Willis
Quaternary Science Reviews 27 (2008) 1723-1732

How can a knowledge of the past help to conserve the future? Biodiversity conservation and the relevance of long-term ecological studies
Katherine J. Willis, Miguel B. Araújo, Keith D. Bennett, Blanca Figueroa-Rangel, Cynthia A. Froyd and Norman Myers
Phil. Trans. R. Soc. B (2007) 362, 175-186

3. Palaeoecologists' fault
   - present their data in a poor and complex way
   - slow to take advantage of the many advances made in Quaternary palaeoecology in the last 25 years
   - data often lack taxonomic, spatial, or temporal precision
   - tend to rely (too heavily) on pollen analysis. Many other fossil 'proxies' preserved – seeds and fruits, conifer stomata, fungal spores, sediment inorganic and organic geochemistry, stable-isotopes, and, in lakes, diatoms, chironomids, cladocerans, etc

What are the Key Advances in Long-Term Ecology

1. Major advances in detailed **pollen and spore morphology** and hence in the taxonomic precision of palaeo-data.

   North-West European Pollen Flora, ever increasing modern pollen reference collections, improved microscopy, new identification aids. For example, Sylvia Peglar has identified over 150 pollen taxa in Holocene lake sediments from Trøndelag.

2. Major advances in **fine-scale sampling** with improved coring equipment and laboratory techniques. Can now sample at 1-2 mm resolution if required (about every 5-10 years).

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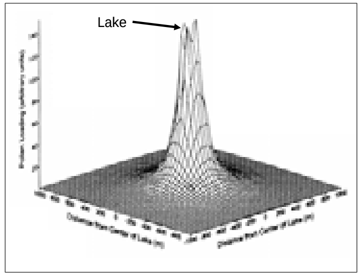
3. Major advances in understanding the **likely source area** of pollen from which the bulk of the pollen preserved in a bog or lake is derived from



Witch's hat - high crown, infinitely wide brim

Pollen loading signal from trees near the lake is an order of magnitude greater than from trees only 200 m away and at least two orders of magnitude greater than from trees 1000 m away.

Davis 2000

Relevant pollen source areas for

small hollow	(5 m radius)	50-100 m,
small lake	(50 m radius)	300-400 m,
medium lake	(250 m radius)	600-800 m

Temporal and spatial scales of vegetation sampled by different sedimentary basins.

Deposits	Basin size (km^2)	Area sampled (km^2)	10,000 yr sediment (m)	Time covered (yr)	Sediment-ation rate ($yr\ mm^{-1}$)	Analogous 'view'
Large lake sediments	>0.05	10^2 - 10^3	5	10^4	2	Small-scale satellite photo
Medium lake sediments	0.01 - 0.05	10^1 - 10^2	5 - 8	10^4	1.25 - 2	Large-scale aerial photo
Small lake sediments	<0.01	10^{-1} - 10^1	5 - 10	10^4	1 - 2	Catchment from fire tower
Forest soil or small hollow	<0.001	10^{-2} - 10^{-1}	1 - 2	10^2 - 10^4	5 - 10	20 x 20 m permanent plot

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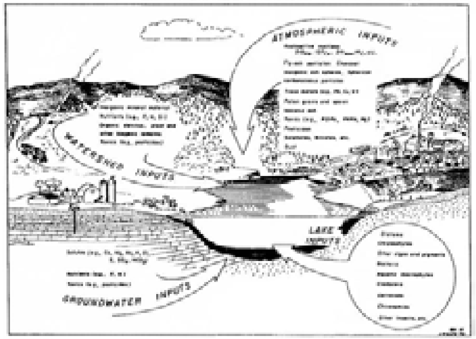
4. Major advances in the **use of lakes** as a long-term record of many palaeoecological variables



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).

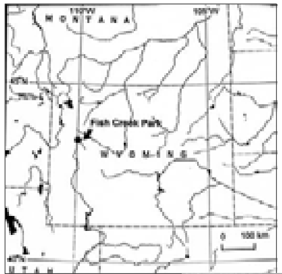
5. Major advances in developing **multi-proxy studies** where many different palaeoecological proxies (e.g. pollen, fungal spores, diatoms, seeds) are studied together on the same sediment core in an integrated and critical way, e.g. Lobsingsee in Switzerland, Kråkenes in Norway.
6. Major advances in **numerical methods** as tools for the summarisation and analysis of complex multivariate long-term ecological data and for the testing of specific hypotheses.
7. Increasing thought about **site selection**, **problem formulation**, and **hypotheses** to be tested by long-term ecological data.

All these advances are **very relevant** to the full and effective use of long-term ecology in conservation and management.

Can Long-Term Ecology Contribute to our Understanding of Landscape History?

Origin of a landscape mosaic in the Rocky Mountains, USA

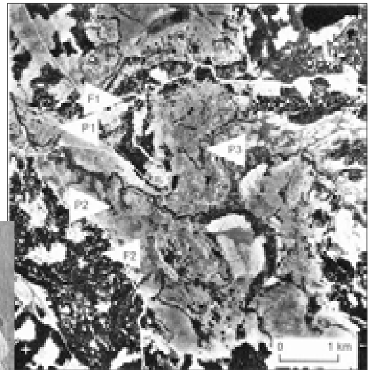
Park-Forest mosaic, Wyoming



Location of Fish Creek Park, Wind River Range, Wyoming.

Beth Lynch

Aerial photo showing core sites in Fish Creek Park and surrounding forest (1:40,000).



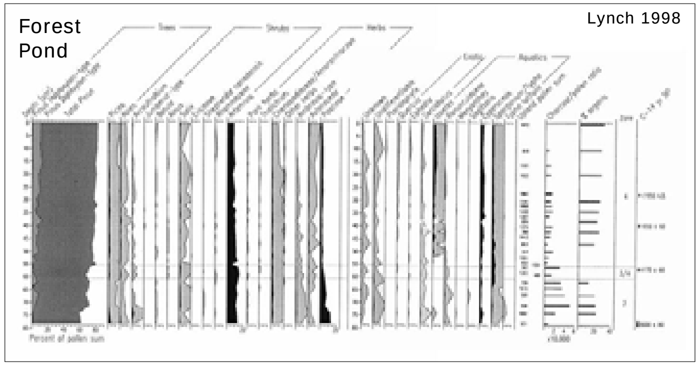
Big Horns, Wyoming

Hypotheses of park origin and expected vegetation histories from park and forest sites.

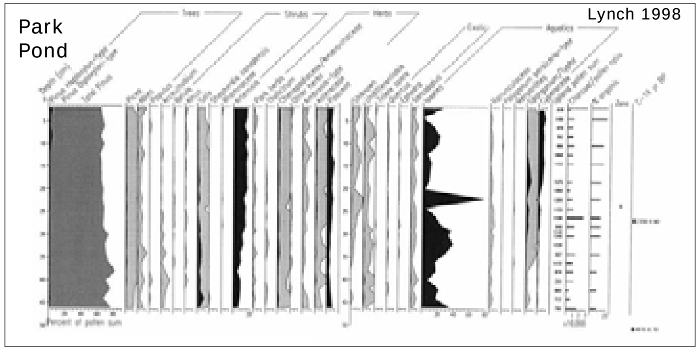
Hypothesis	Expected vegetation sequence at present park and forest sites
Permanent site (e.g. soil factors)	Park: Park vegetation throughout Forest: Forest vegetation throughout *
Remnant (e.g. once all park)	Park: Park vegetation throughout Forest: Park, then forest *
Replacement (e.g. disturbance)	Park: Forest,* then park Forest: Forest vegetation throughout *

* Periods of forest vegetation may have short intervals of non-forested vegetation, following disturbance, but revert to forest vegetation soon after.

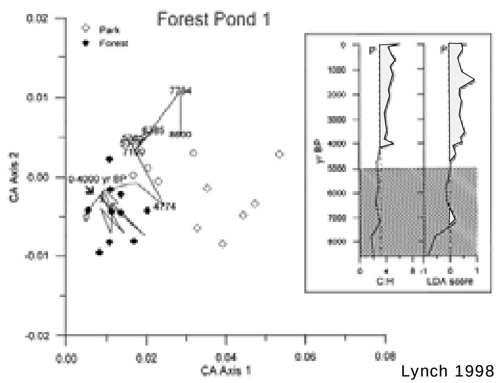
Lynch 1998



Sediment core analysis for Forest Pond 1 in the Wind River mountains of northwestern Wyoming. Shown are pollen percentages, charcoal:pollen ratios, organic content, and ^{14}C dates to 78 cm depth.



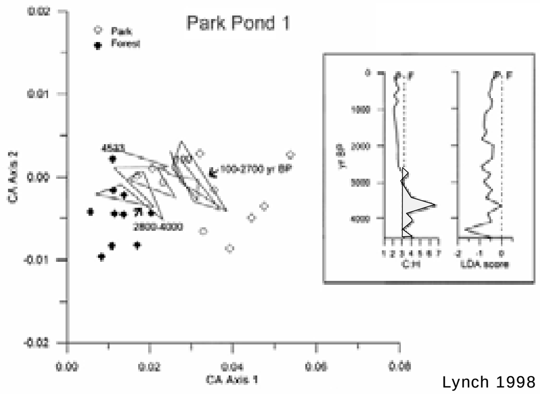
Sediment-core analysis for Park Pond 1. Shown are pollen percentages, charcoal:pollen ratios, organic content, and ^{14}C dates to 47 cm depth.



Lynch 1998

Inset shows changes in C:H (conifer:herb) ratios and linear discriminant analysis (LDA) scores over time; in hatched portion, C:H ratios and LDA scores are less valid indices for separating park and forest vegetation.

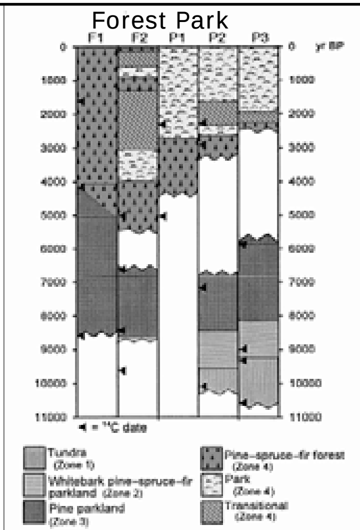
Correspondence analysis (CA) ordination of fossil pollen samples from a sediment core at Forest Pond 1 (connected by line and labelled with dates) and surface samples (diamonds).



Lynch 1998

CA ordination of fossil pollen samples from Park Pond 1 (connected by line and labelled with dates) and surface samples (diamonds). Inset shows changes in C:H (conifer:herb) ratios and LDA scores over time.

Vegetation changes inferred from pollen assemblages at five sites. Gaps represent periods with no sediment record.



Lynch 1998

Hypotheses of park origin and expected vegetation histories from park and forest sites.

Hypothesis	Expected vegetation sequence at present park and forest sites	
Permanent site (e.g. soil factors)	Park: Park vegetation throughout Forest: Forest vegetation throughout *	Rejected
Remnant (e.g. once all park)	Park: Park vegetation throughout Forest: Park, then forest *	Rejected
Replacement (e.g. disturbance)	Park: Forest,* then park Forest: Forest vegetation throughout *	Not rejected

* Periods of forest vegetation may have short intervals of non-forested vegetation, following disturbance, but revert to forest vegetation soon after.

Lynch 1998

Mosaic structure is of major importance to birds and mammals in this landscape. Conservation plans need to understand how the mosaic came about.

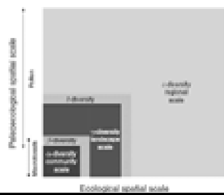
Can Long-Term Ecology Contribute to Understanding Landscape Diversity?

Robert Whittaker

Ecologists increasingly recognise the importance of habitat and landscape diversity (eco-diversity or eco-complexity) in influencing species diversity within landscapes.

Ecologists recognise many types of diversity
- community (α-diversity)
- between community (β-diversity)
- landscape (γ-diversity)
- between landscapes (δ-diversity)
- regions (ε-diversity)

Pollen data potentially relevant to all these scales



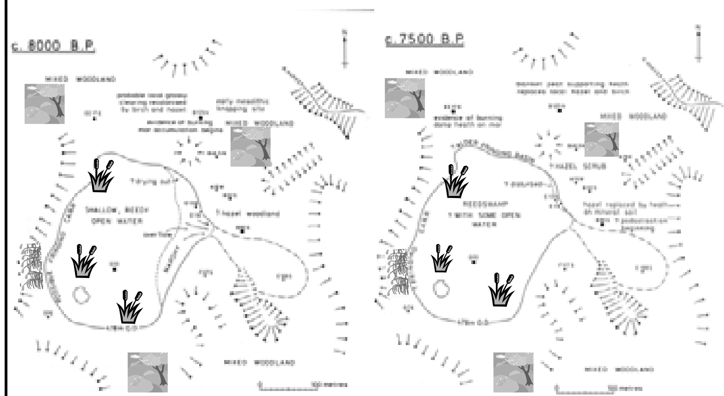
Odgaard 2007

Can reconstruct the **landscape-scale diversity** from long-term ecological data if you have many sites from a small area. Reconstruct past vegetation types first.

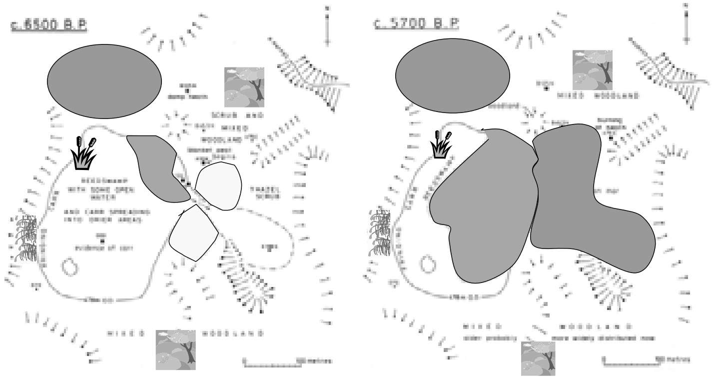
Smith & Cloutman 1988 Phil Trans R Soc B 322: 159-219
Waun-Fignen-Felen, Black Mountain Range of S Wales
Amazingly detailed study with 13 pollen diagrams and over 100 ^{14}C dates from a 15 ha bog

Black Mountains, S Wales

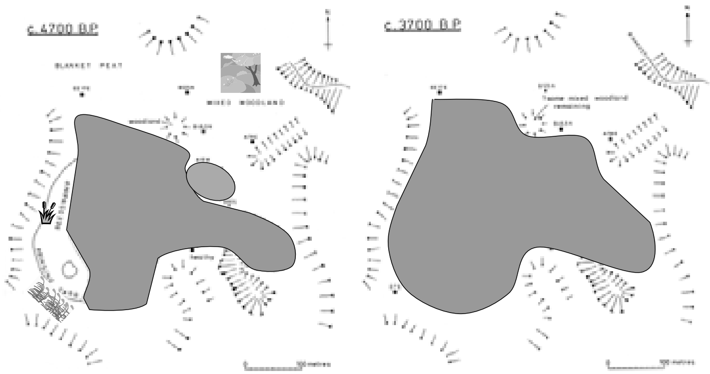
Blanket-mire



Smith & Cloutman 1988



Smith & Cloutman 1988



Smith & Cloutman 1988

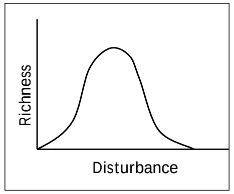
Main vegetation units at Waun-Fignen-Felen area

Age x10^3 (^{14}C yrs BP)	8.0	7.5	6.5	5.7	4.7	3.7
Dryland						
Grassland	+				+	
Betula/Corylus scrub	+	+	+	+		
Corylus woodland	+					
Mixed woodland	+	+	+		+	+
Corylus scrub		+	+			
Total	4	3	3	1	2	1
Wetland						
Reed-swamp	+	+	+	+	+	
Fen carr woodland	+	+	+	+	+	
Blanket bog		+	+	+	+	+
Acid peat bog			+	+		
Damp heath			+			
Total	2	3	5	4	3	1

Decrease in landscape (γ) diversity with expansion of blanket peat

Important implications for landscape management and habitat restoration, especially in oceanic areas.

Can Long-Term Ecology Contribute to Understanding Determinants of Diversity?



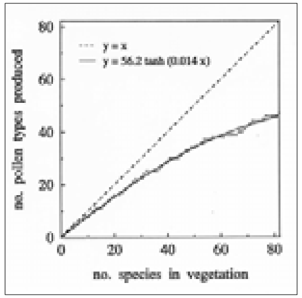
"Disturbance of biotically determined relationships is essential to the generation and maintenance of diversity" at landscape scale (Walker 1989)

Intermediate disturbance hypothesis
J. Connell, J.P. Grime

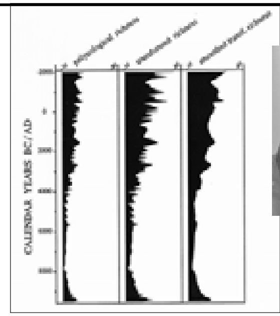
i.e. maximum richness at intermediate disturbances. Prevents development of dominance by any single component, but insufficient to cause extinction of components at landscape scale.

Palynological sample richness, as estimated by rarefaction analysis, mainly relates to landscape (or pollen source area) pollen diversity, namely γ-diversity, depending on size of site and it pollen source areas.

Only discussing **palynological sample richness**. Its relationship to plant species richness is controversial and unclear. Palynological richness is simply a **parameter** estimated from pollen data.



The relationship between floristic richness and palynological richness in the research area of Draved Forest, Denmark. The plot was produced from a list of field-layer species arranged in random order and the corresponding cumulative number of pollen types produced by these (+).

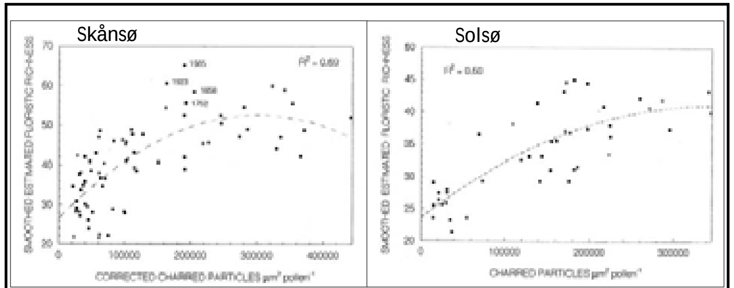


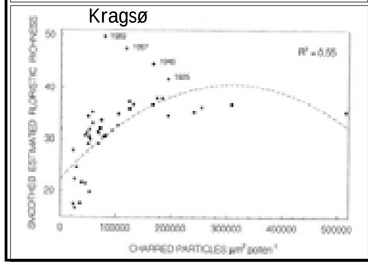
Bent Odgaard 1994

Holocene number of herb and shrub pollen types (palynological richness scores at a total pollen count of 1000), transformed and smoothed (five point weighted filter, weights ⅓, ⅔, 1, ⅔, ⅓) transformed richness at Skånsø north-western Jutland, Denmark. The transformation uses the function of previous figure in an attempt to correct for lack of taxonomic precision.

Odgaard 1994

Smoothed estimated floristic richness for Holocene pollen sequences at Solsø (black line), Skånso (blue line) and Krågsø (red line).

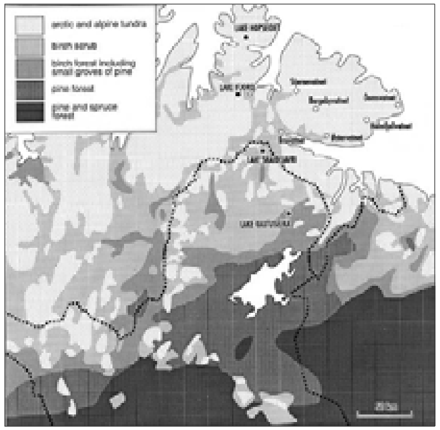




Results **supportive** of intermediate-disturbance hypothesis. Comparable results from Panama, Congo, and New Guinea.

Odgaard 1994

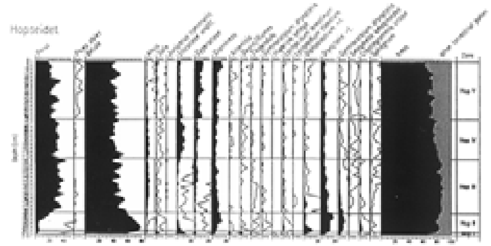
Pollen richness and rate of change



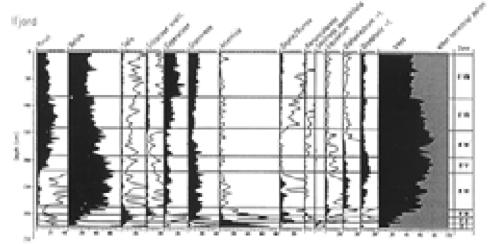
Seppä, 1996

Main vegetation zones in the far north of Fennoscandia and location of the main fossil pollen sites.

Tundra



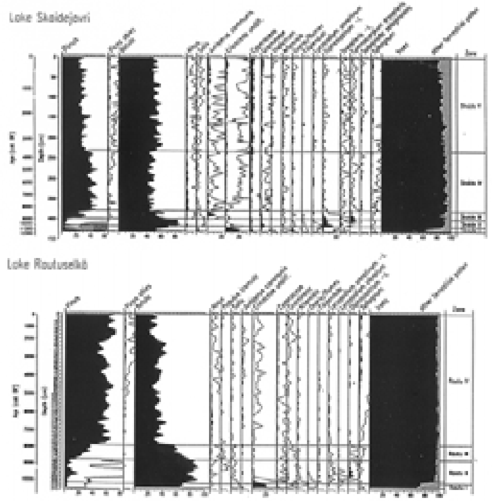
Tundra near *Betula*



Seppä 1998

Betula

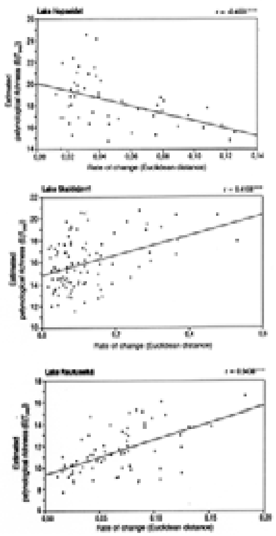
Betula
+ Pinus



Seppä 1998

Estimated palynological richness (rarefaction analysis) for each site and rate-of-change (amount of pollen compositional change per unit time – a measure of change and possibly of disturbance) for four sites in northern Fennoscandia.

Palynological richness plotted against rates of change. The regression line and the correlation coefficient are also shown.



Tundra

Generally open unstable harsh environment

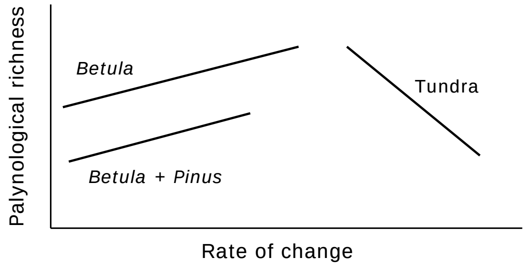
Betula

Generally closed stable environment

Betula + Pinus

Generally closed stable environment

Seppä 1998

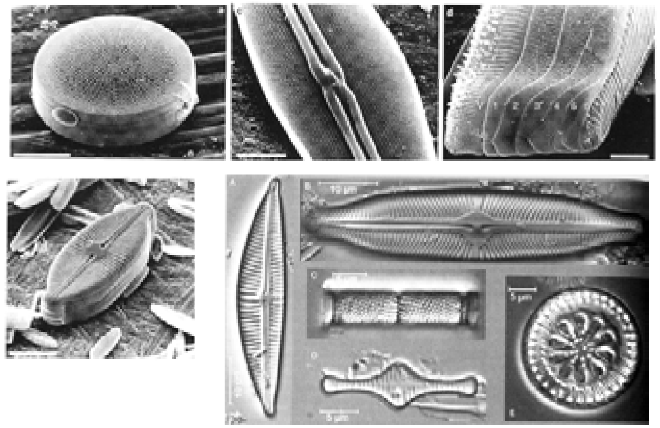


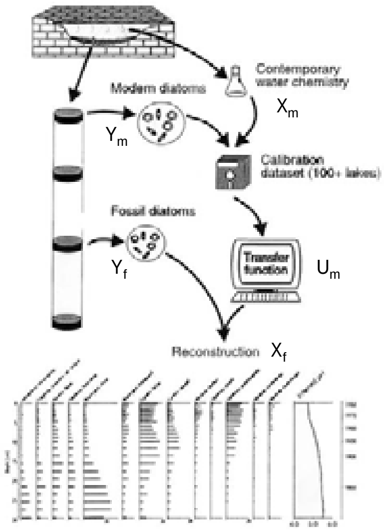
Indicative of high palynological richness at **intermediate** levels of rate of change. Low palynological richness in forested landscapes and in highly disturbed tundra landscapes.

Can Lake History Contribute to Understanding Landscape Dynamics?

Palaeolimnology, especially the study of diatoms preserved in lake sediments, can contribute much to our understanding of landscape dynamics.

Freshwater diatoms - excellent indicators of lake-water chemistry (e.g. pH, total P).

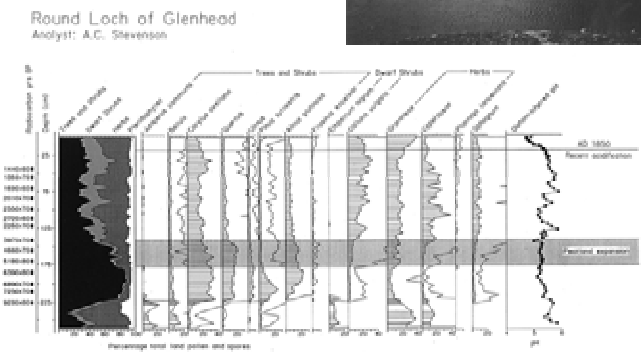




Procedures for reconstructing lake-water pH from diatoms

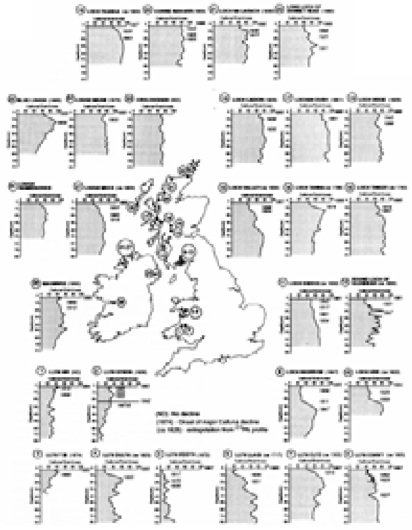
Outline of the transfer function approach to quantitative palaeoenvironmental reconstruction

Rick Battarbee



Heath and blanket-bog loss

1. Upland heath – considerable loss in last 200 years. Many possibly causes.
   (1) 17-19th centuries - high sheep grazing pressure
   (2) Extensive afforestation from 1920s
   (3) Acid deposition, weakening heather
   (4) Atmospheric N deposition, favouring grasses especially *Molinia caerulea*



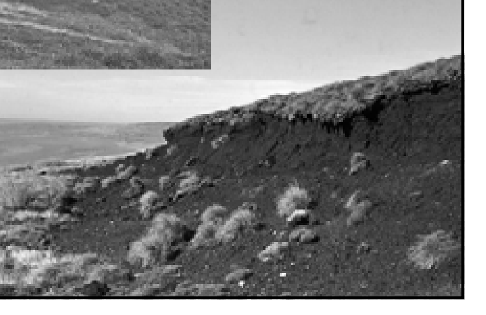
All evidence favours multiple causes (acid deposition, N deposition, land-use change)

Stevenson & Thompson 1993

2. Blanket-bog erosion

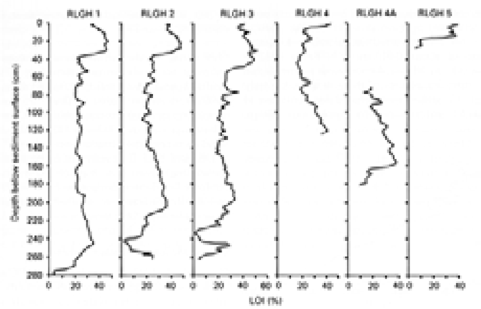
   Causes
   (1) Started AD 1500 - AD 1700
   (2) Grazing and burning
   (3) Loss of *Sphagnum* species by excessive acidification by S and N compounds
   (4) ? Climate change and 'Little Ice Age'

Pen-y-Ghent, Yorkshire



Fountains Fell, Yorkshire

Peat-erosion recorded in lake sediments



Core variability in the Round Loch of Glenhead as demonstrated by loss-on-ignition records.

Cores suggest that peat erosion began in last 200-300 years. Result of climate change and land-use changes?

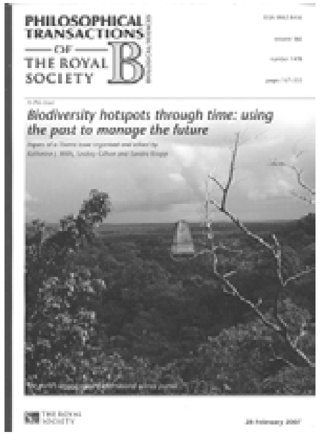
Can Long-Term Ecology Contribute to Other Aspects of Management and Conservation?

YES!

Has, with care, contributed by:

1. Establishing **native status** of particular species
2. Establishing if a particular woodland is '**natural**' or not
3. Providing information on **base-line conditions** for ecosystem restoration
4. Demonstrating **rapid 'regime' shifts** (alternate stable systems) and detecting the critical 'trigger' for these shifts in aquatic and terrestrial systems
5. Demonstrating **differential responses** by species to environmental change, for example at the Late-glacial -Holocene transition
6. Detecting **ecological thresholds and resilience** in relation to management thresholds
7. Documenting 'natural' **variability** in ecosystems
8. Providing **factual basis** for management within natural variability
9. Establishing role of large **infrequent disturbances** in landscape dynamics
10. Providing insights into **tree spreading rates** in relation to climate change and contributing to current debate on '**assisted migration**'
11. Providing basis for establishing if present-day landscape is a result of recent **climate change or cultural impacts**
12. Contributing to current debate about '**re-wilding**' wilderness areas

For examples, see



What Is Natural? The Need for a Long-Term Perspective in Biodiversity Conservation

K. J. Willis and H. J. B. Birks — SCIENCE VOL 314 24 NOVEMBER 2006

Emerging issues in biodiversity & conservation management: The need for a palaeoecological perspective

C.A. Froyd, K.J. Willis — Quaternary Science Reviews 27 (2008) 1723–1732

What are the Challenges?

1. Long-term ecology must **interact closely** with management and conservation biology. Need to speak same language, address same problems, and be appreciative of each other's data and research questions.
2. Long-term ecologists need to take **full advantage** of the many advances in long-term ecology – spatial, temporal, and taxonomic precision, multi-proxy studies, use of lakes, numerical methods, care in site selection, coring techniques, etc.
3. Detailed long-term ecology is very **time-consuming** – must therefore study the best available site for a specific conservation problem. Pilot studies and datings essential but rarely done – appear as a 'waste of time' although are certainly not a waste of time or effort.

What are the Compromises?

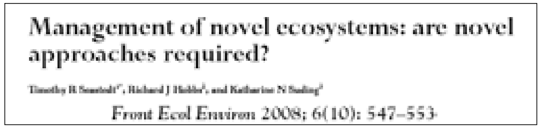
1. May **not** have the 'perfect' site in the landscape of interest relevant to the management question of concern. Long-term ecologists should acknowledge this and not over-interpret their data.
2. Conservationists need to **formulate** their research questions, if at all possible, at the spatial, temporal, and taxonomic scales of long-term ecological data. Some compromises likely here.
3. Testing alternative hypotheses about, for example, the current status of tree-lines, may require the use of dynamic vegetation **models**. Such models, although mathematically and analytically sophisticated, often, by necessity, have to simplify the ecological situation and make compromises between simplicity and numerical solutions and complexity and no numerical solutions.

4. Both long-term ecologists and conservationists should be prepared for 'ecological surprises' in the future.

Williams & Jackson 2007

- Our quickly changing climate may present us with completely new ecological scenarios
- 'no-analogue' communities
- the 'reshuffling of species'
- 'ecological surprises'
- unpredictable interactions between new climate patterns and existing species

5. Most ecosystems today are sufficiently altered in structure and function to be regarded as novel systems.


Management of novel ecosystems: are novel approaches required?

Timothy R Seastedt, Richard J Hobbs, and Katharine N Suding

Front Ecol Environ 2008; 6(10): 547–553

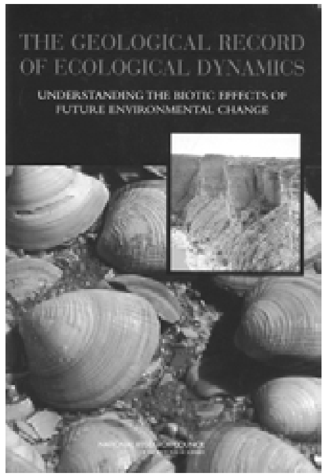
Compromises likely between existing, familiar management approaches and novel, unfamiliar approaches

Conclusions

1. Understanding landscape dynamics in the past as a tool for predicting and managing landscape dynamics in the future needs a strong and effective **interaction** and **collaboration** between long-term ecology and management and conservation.
2. Much to learn from '**lessons from the past**' and to understand '**legacies** from the past'.
3. We should not view modern ecology and long-term ecology as separate entities. View long-term ecology as a **continuum** in time - part of ecology.

4. The **timescales** used to address a research question depend on the ecological processes and organisms of interest (e.g. trees).
5. Conservation biology has embraced the importance of different **spatial scales** but it has yet to do this with **temporal scales**.
6. Many major **challenges** ahead for all of us.

Important and critical part of long-term ecology, as emphasised by the National Research Council's (USA) report on The Geological Record of Ecological Dynamics – Understanding the Biotic Effects of Future Environmental Change (Flessa & Jackson 2005)



Acknowledgements

Kathy Willis

Des Thompson

The late Derek Ratcliffe

Shonil Bhagwat

Hilary Birks

Kari Hjelle

Cathy Jenks