Faunal evidence

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Thanks to Oliver Heiri, Jenny Watson; Tim Atkinson, Mark Chapman
1. Evidence from faunal assemblages
2. Sources of uncertainty in palaeoclimate reconstructions
3. Addressing uncertainty
1. Faunal assemblage evidence

<table>
<thead>
<tr>
<th>Proxy</th>
<th>Sediment</th>
<th>Climate parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertebrates</td>
<td>Cave, various</td>
<td>No direct quantitative reconstructions</td>
</tr>
<tr>
<td>Beetles</td>
<td>Peat, Lake, Alluvium</td>
<td>Max temp of warmest month&lt;br&gt;Max temp coldest month&lt;br&gt;Temp range&lt;br&gt;Moisture?</td>
</tr>
<tr>
<td>Chironomids</td>
<td>Lake</td>
<td>Summer air temp</td>
</tr>
<tr>
<td>Cladocera</td>
<td>Lake</td>
<td>Summer air/water temp&lt;br&gt;Lake depth</td>
</tr>
<tr>
<td>Mollusca</td>
<td>Alluvium, lake</td>
<td>Max temp of warmest month&lt;br&gt;Max temp coldest month&lt;br&gt;Temp range</td>
</tr>
<tr>
<td>Ostracoda</td>
<td>Lake</td>
<td>Salinity/lake level</td>
</tr>
<tr>
<td>Testate amoebae</td>
<td>Peat</td>
<td>Water table depth (Summer P-E)</td>
</tr>
<tr>
<td>Foraminifera</td>
<td>Marine &amp; coastal</td>
<td>Sea surface temperature&lt;br&gt;Sea level</td>
</tr>
</tbody>
</table>

Also stable isotope, geochemical proxies contained in remains of molluscs, ostracods, foraminifera,
Key characteristics for faunal palaeoclimate indicators

- Sensitive to climatic or climate-related variable(s) e.g. stenotherms
- Rapid response
- Abundant in environment
- Abundant in sediment – temporal resolution
- Niche & habitat specific with known ecology
- Identifiable to low taxonomic level
- Deposition in-situ
- Diversity
- Distribution and development of technique
Chironomids

Adult

Larva

Fossil head capsule
Testate amoebae
Reconstruction of climate change from faunal assemblages

Fossil assemblages from sediments → ‘Transfer function’ → Inferred climate change

Modern assemblages and environmental data
Quantitative reconstruction methods

- Regression techniques (linear and unimodal-based)
- Bayesian calibration models
- Modern analogue techniques
- Mutual climatic range method
- Indicator taxa
- Which model is ‘best’ for a particular application?
Neogloboquadrina coiling directions: A robust climate proxy for high-latitude SST.

(Kucera, 2007)

Tephra isochrons: Testing climate synchronization

Indicator species
Regression and MAT approaches

• Assemble modern regional training set (typically n >100, maximise gradient, even spread of sites across gradient, minimise variation in other variables)
• Evaluate strength of species-environment response with (un)constrained ordination (CANOCO or similar software)
• Use leave-one-out cross-validation to assess performance of model - $r^2$, root mean squared error of prediction (RMSEP), maximum and mean bias. ($C^2$ software practically standard (Juggins 2003))
• Models typically tested:
  – Unimodal-based: Weighted averaging (WA), WA-partial least squares (WA-PLS), maximum likelihood (ML)
  – Linear based: PLS, principle components regression
  – Modern analogue (MAT)
• ‘Best’ transfer function used to infer climate variable from fossil assemblages
• Sample specific errors for fossil samples calculated by boot-strapping (1000 cycles)
Selecting the ‘best’ model – performance in cross validation of modern data

Table 2  Summary of performance of different models for water table using the full dataset, based on jack-knifed (‘leave-one-out’) cross-validation and in order of performance assessed by the root mean squared error of prediction (RMSEP). Only the ‘best’ version of each main approach is shown. Figures in parentheses are following exclusion of outlier samples identified from the WAPLS analysis.

<table>
<thead>
<tr>
<th>Model</th>
<th>$R^2$</th>
<th>Average bias</th>
<th>Max. bias</th>
<th>RMSEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAPLS Component 2</td>
<td>0.60 (0.71)</td>
<td>0.31 (0.05)</td>
<td>26.6 (8.5)</td>
<td>7.64 (5.63)</td>
</tr>
<tr>
<td>WA-Tol (inverse deshrinking)</td>
<td>0.60 (0.67)</td>
<td>0.56 (0.27)</td>
<td>30.6 (9.5)</td>
<td>7.65 (5.97)</td>
</tr>
<tr>
<td>PLS Component 4</td>
<td>0.59 (0.68)</td>
<td>0.23 (0.02)</td>
<td>26.1 (8.2)</td>
<td>7.78 (5.86)</td>
</tr>
<tr>
<td>WMAT</td>
<td>0.59 (0.74)</td>
<td>-0.48 (-0.40)</td>
<td>37.5 (9.6)</td>
<td>7.90 (5.60)</td>
</tr>
<tr>
<td>WA (inverse deshrinking)</td>
<td>0.55 (0.66)</td>
<td>0.30 (0.09)</td>
<td>30.8 (6.8)</td>
<td>8.13 (6.88)</td>
</tr>
</tbody>
</table>

(a) with, and b) without, outlier samples

“In any case, a performance with a RMSEP of ±1.5°C should be considered extremely satisfactory since the actual standard deviation of the “modern” mean SST is >1.5°C in the largest part of the World Ocean, and throughout most of the North Atlantic”

(Guiot & de Vernal, 2007).

(Kucera, 2007)
Bootstrapped error estimates for reconstruction

Hendon et al. (2001) The Holocene
July air temperature reconstructed using a Bayesian multinomial calibration model, (Bummer)

Sample-specific posterior distributions
Darker shades = higher posterior densities.

Mutual climatic range (beetles, sometimes molluscs)

- Based on species distributions from literature and modern climate data
- Temp reconstruction using assumed Gaussian distribution
- Range determined by number of taxa used in reconstruction,
- Predicted ranges for TMIN generally much larger than TMAX (e.g. beetles inactive in winter)
- Comparison between MCR reconstruction and modern shows it is accurate (but possible over-estimation of TMAX)
- Can produce large ranges therefore only really suitable for large magnitude changes
- Recent work on improving accuracy. e.g. Huppert and Solow (2004), using Gaussian probability curves; Bray et al. (2006) ubiquity analysis
Maximum Likelihood Method (MLE)

Allows an estimate of robustness of envelopes to be tested and makes necessary adjustments.

Fig 1. LGM temperature reconstruction for the lower Awakere Valley for mean February (summer) temperature.
2. Sources of uncertainty in climate reconstruction from faunal assemblages

Fossil assemblages from sediments → Laboratory methods → Modern assemblages and environmental data

Ecosystem dynamics and sedimentary processes

‘Transfer function’

Data analysis methods

Ecological processes and measurement

Chronologies

Inferred climate change

Understanding of these is variable and quantification of the uncertainty even more so….
Laboratory techniques

- Extraction
- Counting
- Taxonomy

e.g. How many head capsules for chironomid temperature reconstruction?
Ecological processes and measurement
(e.g. Telford & Birks 2005; Belyea 2007)

• Uncertainty in environmental data – measurement, microclimate vs ‘macro’ climate, seasonality
• Other controlling variables
• Gradients and sampling - incomplete/uneven sampling, adequacy of response functions used
• the niche concept - neutrality, spatial autocorrelation, fundamental vs realised niches
Ecological understanding is critical
e.g. annual cycle of planktonic foramifera

(Kucera, 2007)
Other controlling variables
e.g. Effect of lake depth on temperature estimation from chironomids

Species responses – HOF response models for chironomids
Beetles in New Zealand

Does the sine curve provide a satisfactory explanation of the data?

July data: good fit

Feb data: skewed! Other climatic parameter may be important – moisture/summer drought?
Application of modern relationships to fossil assemblages
(Belyea 2007)

• Poor/missing analogue species and assemblages
• Validity of space for time substitution (e.g. stability of relationships with all variables)
• Ecological dynamics –, historical effects, internal processes/structure interaction with external forcing, lags and non-linear responses of communities compared to rates of climate change
Uniformitarian assumptions: poor modern analogues

E.g. Testate amoebae: reconstructed water table with/without D. pulex

In general, lack of D. pulex analogue leads to drier reconstructed water tables ... but magnitude is highly variable.
Some chronological issues

- material dated vs faunal remains
- dating errors (and reservoir in marine samples)
- age-depth models – assumptions, errors for samples between dated horizons
- temporal resolution - what does single sample really represent in terms of time?
2. Addressing uncertainty in reconstructions from faunal assemblages

1. Uncertainty estimates for individual samples

2. Replication, comparison and compilation of records

Fossil assemblages from sediments

Ecosystem dynamics and sedimentary processes

Data analysis methods

Inferred climate change

Laboratory methods

Modern assemblages and environmental data

Ecological processes and measurement

Chronologies
Addressing uncertainty

- Uncertainty in modern species-environment relationships
  - cross validation to assess model performance
  - Boot strapped error estimates for fossil samples
  Both make assumptions and under-estimate actual uncertainty (Belyea, 2007)

- Above, plus uncertainty over non-climatic influences on the sedimentary record (‘Total’ uncertainty) by comparisons of:
  - reconstructions using different models
  - multiple records
  - multi-proxy reconstructions
  - between reconstructions and instrumental climate data
Which one is the ‘best’ reconstruction?

Should we calculate a mean or median from all reasonable models?

How would we then estimate uncertainty from these multiple reconstructions?
Combining multiple records
Chironomid July T
Is stacking and ‘averaging’ the best way to account for non-climate influences?

Can multiple records be used to estimate ‘total’ uncertainty?

How do we combine uncertainties from individual records?

How do we deal with chronological uncertainties?

e.g. Average of 12 records from northern Britain (Charman et al, 2006)

Dark blue bands are independently derived lake level high stands
Comparison between MCR and chironomid transfer function reconstruction for Lough Nadurcan, Ireland (J. Watson, unpubl. data)

Mismatch between proxies may require re-evaluation of estimated uncertainties

Systematic difference between proxies suggests they are recording slightly different parameters....
Can/should we combine estimates and uncertainties from different proxies?

Should we use only (parts of?) selected records, based on ecological understanding?

Lotter et al. (2000) Palaeo
Comparisons with instrumental data

Cladocera-based summer T
(Kattel et al, 2008, Palaeo³)

Chironomid-based July T
(Larocque & Hall, 2003, J. Paleolim.)
Comparisons with instrumental meteorological records

How do we build-in chronological uncertainties?
Can we use proxy-instrumental data comparisons to estimate uncertainty in palaeo-reconstructions?
How to take account of autocorrelation in unevenly spaced, smoothed data

r=0.72
Conclusions/comments

• Huge range of faunal indicators of past climate change
• Uncertainties at all stages of process – need to assess which are the largest uncertainties
• Do we need to understand the detail of all uncertainties?
• Are data comparisons and compilations the best way to take account of total uncertainties?
• Some methodological issues
  – How to use multiple records and data comparisons to estimate ‘total’ uncertainty
  – Evaluation and weighting/rejection of records
  – How to combine uncertainties from multiple records
  – How to build-in chronological errors
  – How to determine statistical significance of trends and correlations