What drives long-term biodiversity change?

New insights from combining economics, paleo-ecology and environmental history.

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Links to policy

- Biodiversity conservation policy: need to understand drivers of change and **particularly** the interaction between economic/environmental/social systems
- National park/water quality management:

Search for “ideal” landscapes

Search for “reference” ecosystem conditions

Overview of paper

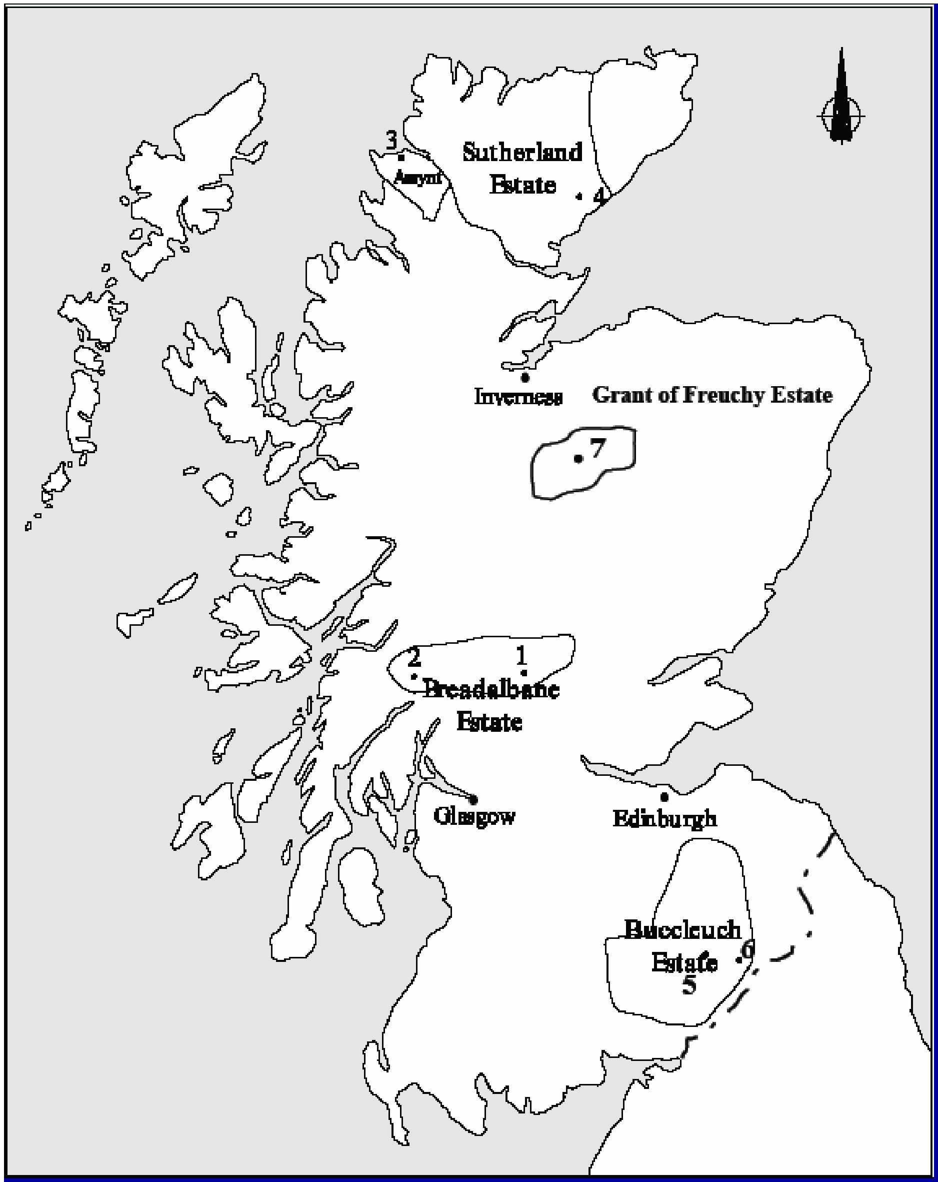
- What’s the problem? Link between “biodiversity” change and agriculture over a 400 year period
- Economic, environmental and social drivers
- Combination of paleo-ecological and historical research to set up a data base
- Use of panel data models to analyse this

What drives biodiversity change?

- Most economic analysis has been rather short-term or simply cross-sectional
- Our work looks across a range of sites in the Scottish uplands over a c400 year period
- Agriculture the main land use over this period
- What will determine biodiversity change? Prices, property rights, technology, wars or environmental factors? Which factors dominate in which periods? What does this tell us about how current policy should be designed??

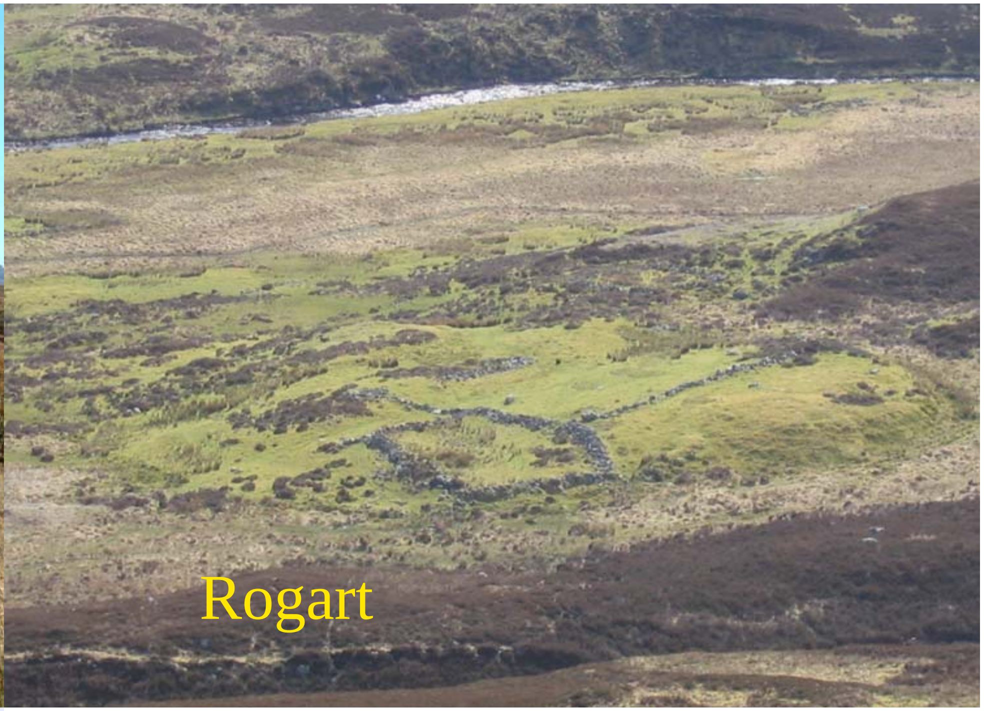
Outline of our approach

- Site selection
- Pollen analysis and dating of peat layers to estimate B_{it}, an estimate of the number of plant species at site *i* in time period *t*
- Historical analysis of estate records etc to build up data base on prices of main agricultural products; technology changes; land holding and land use changes; “extreme civil events”
- Environmental variables = historical climate series plus extreme weather events
- Use panel data models to analyse



Locations of all sites investigated in project. *Breadalbane Estate*: (1) Leadour farm & shieling, Loch Tay, (2) Corries shieling, Glenorchy; *Sutherland Estate*: (3) Glenleraig farm & shieling, Assynt, (4) Rogart farm & shieling, Sutherland; *Buccleuch Estate*: (5) Bush of Ewes farm, Ewesdale, (6) Greenshiels shieling/farm, Liddesdale; *Grant of Freuchy Estate*: (7) Rynuie farm/shieling, Abernethy.


Glenleraig


Rogart

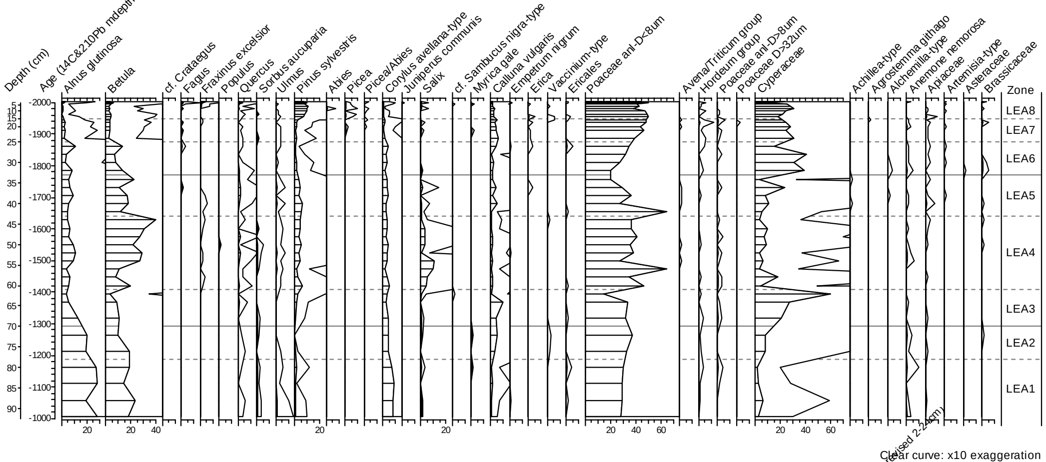

Corries


Leadour

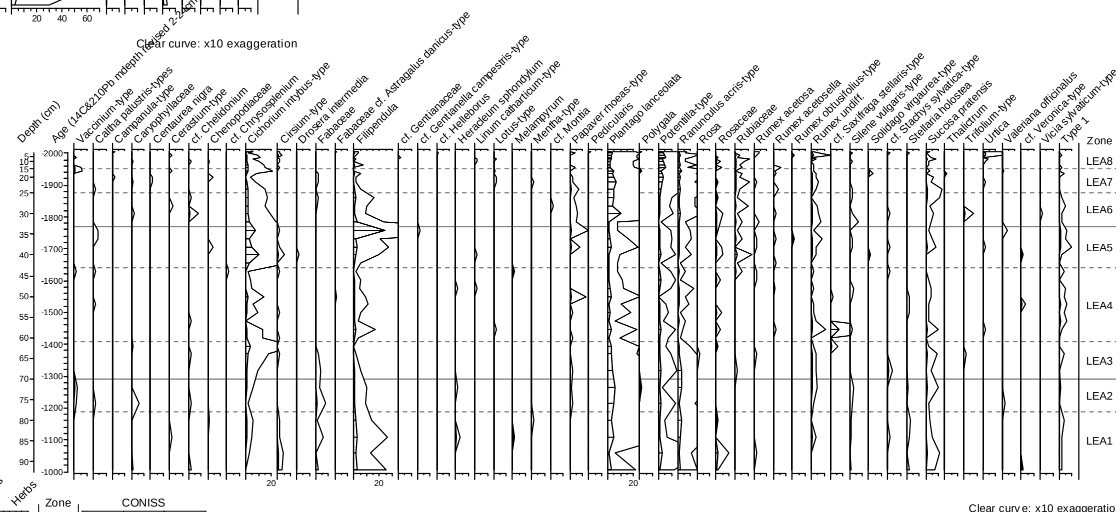
Pollen analysis

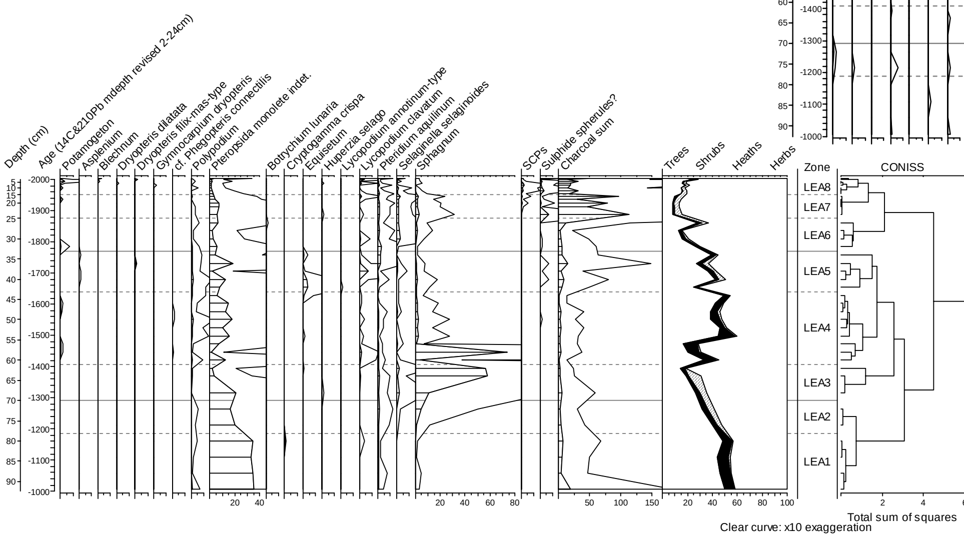
- Take peat cores in suitable locations at each site
- Radiocarbon and lead 210 dating of “layers”
- Picks up a “signal” of between 50-1000 metres radius
- Estimate number of plant species in each layer (ie at each date) using pollen (nb – an imperfect and inexact process)
- Can also look at changes in which species are present over time

Vegetation change: pollen diagrams…

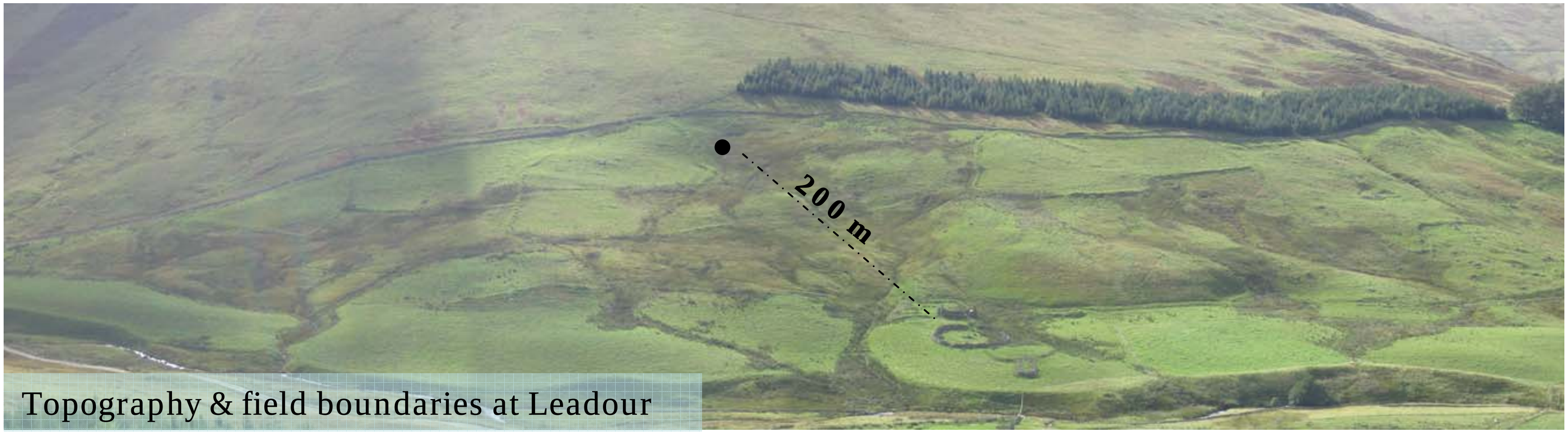


Full percentage pollen diagram for Leadour with zonation





Spatial resolution

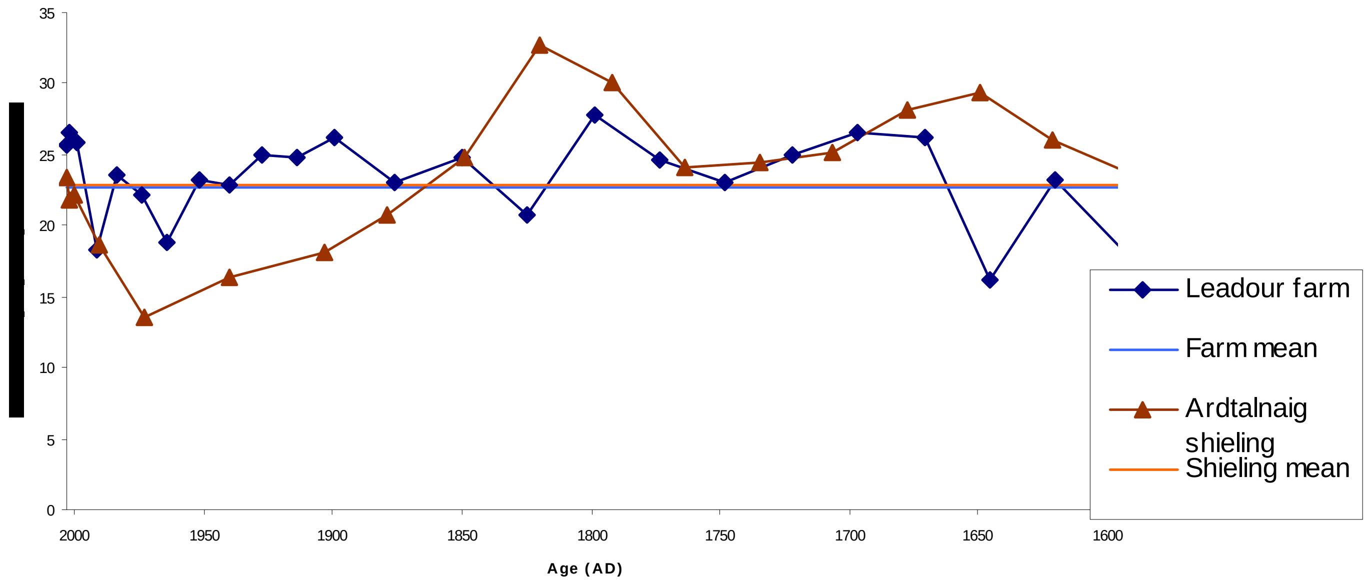


Topography & field boundaries at Leadour

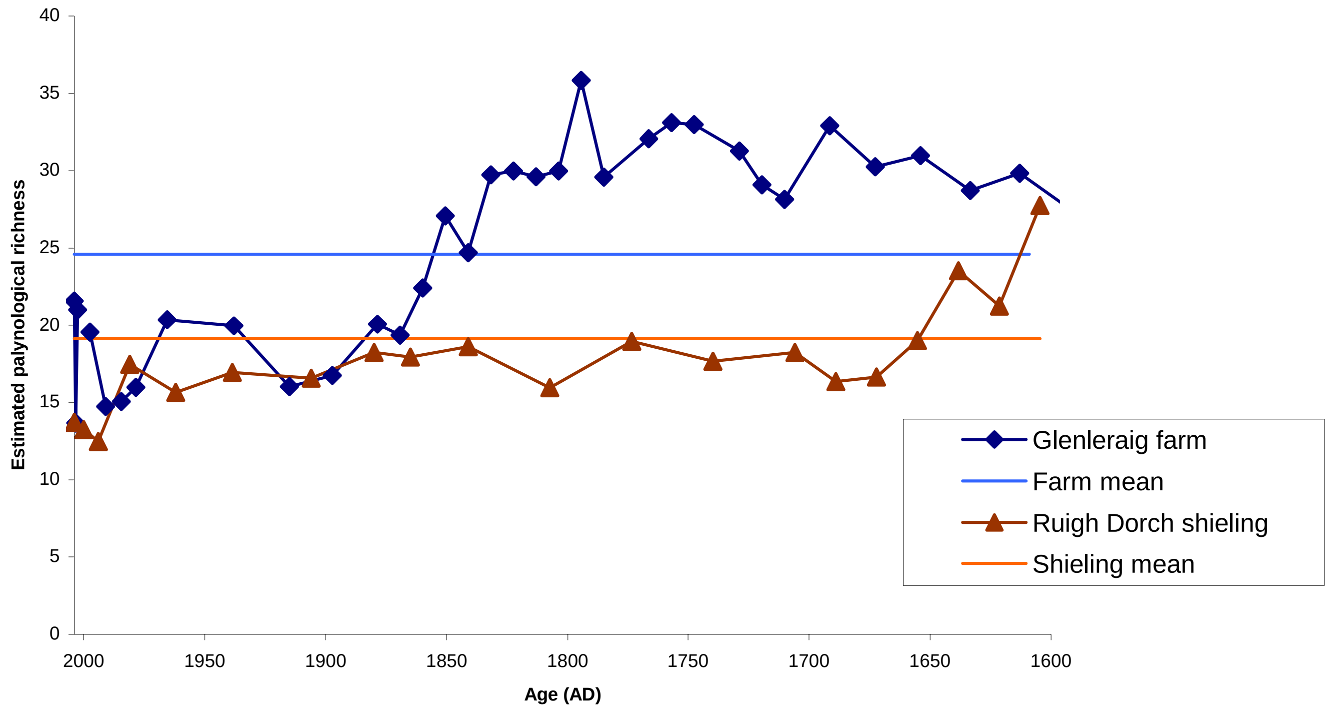
- Small pollen sites within field systems/area of use
- Maximise pollen signal from land-use of interest
- Pollen from 50-100 m dominant, possibly 300-1000 m in open conditions

View over Glenleraig shieling (Ruigh Dorch)

Pollen analysis of number of species, Loch Tay sites, 1600-2000



North West Highlands sites



Explanatory variables

- just about all had to be “discovered” by research team, through examination of primary documents eg estate records

- aimed to compile a panel data set across years and sites for:
  - Cattle and sheep prices (regional markets, primary sources)
  - Arable prices: barley (bere) (regional fiars prices, primary sources)
  - Technology changes eg introduction of new animal breeds
  - Changes in land use, land ownership and tenancy
  - “extreme” civil events (eg war, famines) and “extreme” weather events

- environmental variables – temperature and rainfall plus extreme weather incidents.

- Problems over missing data, and large variability in what was recorded (esp. animal sales)
- Led to use of "20 year time slices" as unit of analysis → also necessary for early-period pollen data
- No data on stocking density before 1860, and rather dodgy even after this date (but the "ideal" variable, ecologically)
- Included lagged *B* variable to pick up ecological spill-overs
- may be experimenting with other representations of pollen data as alternative dependent variables (eg PCA scores) in future

Variable Name	Meaning	Main sources	**Type of data**
Dependent Variable:			
S_{it}	estimated species count at site *i* in year *t*	Pollen analysis	Continuous
Explanatory Variables:			
Lagged diversity	Species diversity estimate in previous 20 year period	Pollen analysis	Continuous
Management			
Site intensity	Intensity of use through year (5=year round; 1= abandoned)	Estate records	categorical
Size change	Property amalgamation or split	Estate records	Count per 20 yr period
Management change	Eg enclosures, draining	Estate records	Count
Animal issues 1	Disease	Estate records	Yes/no
Animal issues 2	New breeds introduced	Estate records	Yes/no
Prices			
Oats	Regional market price	Fiars data, estate records	In £/240
Bere (barley)	Regional market price	Fiars data, estate records	In £/240
Sheep	Regional market price	Estate records; RHAS, estate records	In £/240
Cattle	Regional market price	Estate records; RHAS	In £/240
Wages	Agricultural wages	various	In £/240
Tenure			
Owner change	Change in ownership of site	Estate records	Yes/no
Occupier change	Change in tenant farmer	Estate records	Yes/no
Environmental			
Temperature	Mean monthly	English data	Degrees C
Rainfall	total annual	English data	mm
Extreme weather events	Storms, floods unusual enough to be recorded.	Estate records	Count
Other			
Extreme civil events	War, disease, famine etc	Estate records	Count

- The model we want to estimate can be written as

$$B_{it} = \alpha B_{i,t-1} + bQ_{it} + S_{it}\delta + c_i + u_{it}$$

- But, animal numbers is not observable.
- Instead, we use prices to proxy for increased grazing pressure.

- Problem: What we observe is equilibrium prices, that are most likely an endogenous (market) outcome.
- So, we use demand shifters that are correlated with prices, but uncorrelated with biodiversity change other than their effects through grazing pressures, as instruments.
- We control for site-specific effects by introducing dummies (fixed effects).
- We account for the potential endogeneity of the lagged dependent variable by using its lagged value as an instrument (*sequential moment restrictions*).

Estimation

- 2SLS and Fuller's LIML with *B_{it-2}*, *war, popenglish*, *union*, *refrigeration* and *pbere* as instruments.
- Tests: The instruments used are exogenous (Sargan over-identifying tests) and strongly correlated with the endogenous variables (first stage diagnostics).

Results

TABLE Two: The effect of economic activity on biodiversity

Dep. variable: *Biodiversity index (B_t)*	*(1)* **2SLS**	*(2)* **Fuller-LIML**	*(3)* **2SLS**	*(4)* **Fuller-LIML**	*(5)* **Fuller-LIML**	**(6) Fuller-LIML**
B_{t-1}	0.571** (3.93)	0.571** (3.87)	0.573** (3.90)	0.574** (3.83)	0.579** (3.91)	0.583** (3.89)
pcattle	-0.006** (-2.16)	-0.006** (-2.16)	-	-	-0.006** (-2.06)	-
psheep	-	-	-0.07** (-2.08)	-0.07** (-2.07)	-	-0.07* (-1.98)
sizechange	0.607 (0.53)	0.607 (0.53)	0.609 (0.53)	0.610 (0.54)	-	-
mgtchange	-0.092 (-0.41)	-0.092 (-0.41)	-0.079 (-0.35)	-0.079 (-0.35)	-	-
andisease	-0.605 (-0.55)	-0.607 (-0.55)	-0.583 (-0.53)	-0.585 (-0.53)	-	-
annewbread	1.583 (1.12)	1.582 (1.12)	1.662 (1.17)	1.661 (1.17)	1.296 (1.05)	1.388 (1.12)
mgtinten	0.515** (2.31)	0.514** (2.30)	0.505** (2.25)	0.504** (2.24)	0.504** (2.33)	0.493** (2.26)
extrweather	-0.229 (-0.63)	-0.229 (-0.63)	-0.222 (-0.60)	-0.222 (-0.61)	-	-
extrcivil	-0.095 (-0.13)	-0.094 (-0.13)	-0.118 (-0.17)	-0.117 (-0.17)	-	-
constant	8.563* (1.89)	8.565* (1.87)	8.546* (1.85)	8.549* (1.82)	8.293* (1.80)	8.238* (1.75)

In words….

- Both sheep and cattle prices negatively and significantly linked to biodiversity change
- Implication is that, over time and across sites, higher stocking rates meant lower plant diversity
- Management intensity also matters: abandonment decreases biodiversity.

- Previous period’s diversity significantly and positively linked to current period’s diversity
- But NO significant effects from changing technology (eg new breeds, liming), enclosure or change in property rights/ownership
- And NO significant direct effects from changes in climate or extreme weather events.

Conclusions

- Combination of historical, palaeo-ecological and economic analysis can give new insights into a topical question
- Not something we have seen done before. Data problems probably explain why (although would have been easier to do it, in some ways, for English sites).
- Shows that “modern” ecological thinking is right, in the sense that higher stocking densities reduce biodiversity. Finding on effects of abandonment also fits this theory.
- We show that economic drivers have been the most important factor over time for these upland, agricultural sites ➔ policy implications.

Extensions?

- Compare current ecological “star rating” with ecological history
- Relate current preferences for landscape change/conservation to peoples’ awareness of environmental time-line at that site.

Policy Implications (general)

- May change what we want to achieve
- May change how we try and achieve it.

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