Science of the Total Environment 568 (2016) 381–390

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Long-term predictions of ecosystem acidification and recovery

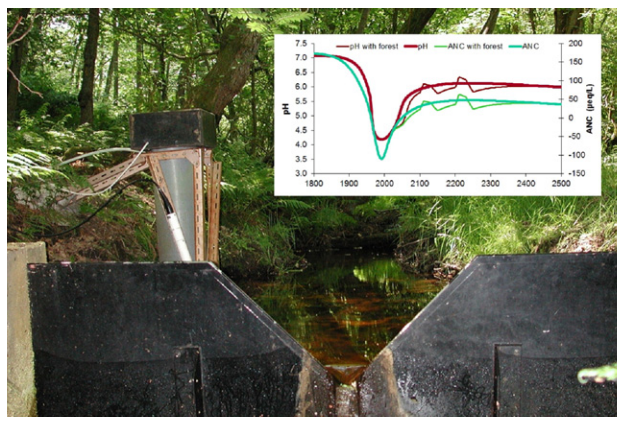
Richard A. Skeffington [a,*], B. Jack Cosby [b], Paul G. Whitehead [a,1]

[a] Department of Geography and Environmental Science, University of Reading, PO Box 227, Reading RG6 6DW, UK
[b] Centre for Ecology and Hydrology, Environment Centre Wales, Bangor LL57 2UW, UK

HIGHLIGHTS

- Modelled the effects of acid deposition on a forested catchment for 500 years
- Current emission reductions allow 250-year recovery; then acidification resumes.
- Catchment accumulates N, nitrate leaching increases.
- Modelled forest growth reduces stream NO_3 and acidity, but acidifies soil.
- Soil validation data indicate acidification may be faster than model predicts.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 29 March 2016
Received in revised form 6 June 2016
Accepted 6 June 2016
Available online 12 June 2016

Editor: D. Barcelo

Keywords:
Modelling
Catchment
Watershed
Forest
Nitrogen
Acidity

ABSTRACT

This paper considers the long-term (500 year) consequences of continued acid deposition, using a small forested catchment in S. England as an example. The MAGIC acidification model was calibrated to the catchment using data for the year 2000, and run backwards in time for 200 years, and forwards for 500. Validation data for model predictions were provided by various stream and soil measurements made between 1977 and 2013. The model hindcast suggests that pre-industrial stream conditions were very different from those measured in 2000. Acid Neutralising Capacity (ANC) was $+150$ μeq L^{-1} and pH 7.1: there was little nitrate (NO_3). By the year 2000, acid deposition had reduced the pH to 4.2 and ANC to c. -100 μeq L^{-1}, and NO_3 was increasing in the stream. The future state of the catchment was modelled using actual deposition reductions up to 2013, and then based on current emission reduction commitments. This leads to substantial recovery, to pH 6.1, ANC $+43$ μeq L^{-1}, though it takes c. 250 years. Then, however, steady acidification resumes, due to continued N accumulation in the catchment and leaching of NO_3. Soil data collected using identical methods in 1978 and 2013 show that MAGIC correctly predicts the direction of change, but the observed data show more extreme changes – reasons for this are discussed. Three cycles of forest growth were modelled – this reduces NO_3 output substantially during the active growth phase, and increases stream pH and ANC, but acidifies the soil which continues to accumulate nitrogen. The assumptions behind these results are discussed, and it is concluded that unmanaged ecosystems will not return to a pre-industrial state in the foreseeable future.

* Corresponding author.
E-mail address: r.a.skeffington@reading.ac.uk (R.A. Skeffington).
[1] Present Address: School of Geography and the Environment, University of Oxford, South Parks Road, Oxford OX1 3QY, UK.

http://dx.doi.org/10.1016/j.scitotenv.2016.06.033
0048-9697/

1. Introduction

The effects of acid deposition remain a significant environmental problem, even though deposition has reduced considerably in many parts of the world. Although there is still much to learn, we now have a good understanding of the major acidification and recovery mechanisms for sensitive soils and waters, encapsulated in models of various kinds. We also have some good long-term data, which is becoming commensurate with the timescales of ecological change induced by changes in atmospheric deposition. The time seems right to explore the long-term consequences of acid deposition given current knowledge, and to ask whether the data we have are sufficient to constrain our predictions of those consequences so that meaningful statements can be made. This paper is an attempt to answer those questions using a calibrated acidification model and long-term data from a catchment in the UK. A single catchment can only serve as an example given the huge variety of climates, vegetation, soils, deposition changes etc., but its reactions can still provide useful insights. For instance, Skeffington and Brown (1992), used this approach to predict that one consequence of declining sulphur deposition would be lower base cation concentrations in recovering surface waters, and that this could cause biological problems. Controversial at the time, this prediction has subsequently been borne out by observations in many places (e.g. Battarbee et al., 2014; Stoddard et al., 1999).

There have been many acidification modelling studies involving projections into the future (e.g. Evans et al., 1998; Ferrier et al., 2003; Helliwell et al., 2003; Jenkins et al., 1990). Usually the time period concerned is 50 years or less, because of a well-justified feeling that predictions become too uncertain over longer periods. This paper is different: it extrapolates for 500 years. It uses data from a small (0.93 km^2) forested catchment in southern England. The MAGIC acidification model was calibrated to the catchment for the year 2000, run back in time for 200 years to assess pre-industrial conditions and forward in time for 500 years to explore future trajectories, given current (2016) knowledge of deposition trajectories. Extrapolating for 500 years may seem unduly speculative in view of the uncertainty over likely environmental change during that time, but the aim of the work is not to make predictions, but rather to explore the implications of current knowledge, and the credibility of current assumptions in the long term. Because observed data on the catchment span 36 years with dramatic changes in deposition, it is possible to apply validation tests to check whether the model predicts the right direction and magnitude of observed change. As well as changes in stream chemistry, a set of soil samples taken in a precise location in 1978 and again in 2013 is used for this purpose. The results are used to discuss the long-term implications of continued low levels of acid deposition for such unmanaged catchments.

2. Methods

2.1. Study site

The study was conducted in the Tillingbourne Catchment in SE England. The catchment is described in detail in Hill et al. (2002): a brief summary follows. The Tillingbourne catchment is located 7 km south west of Dorking in SE England, Latitude 51° 11′ N., Longitude 0° 22′ W. (Fig. 1). It consists of a valley sloping northwards at an angle of about 3°, cut into the dip slope of Leith Hill (297 m), the highest point of SE England. There are no motor roads or habitations in the catchment, which is composed of sedimentary rocks of Cretaceous age, the Lower Greensand Group. The Atherfield Clay which outcrops in the bottom of the valley consists of shales and mudstones which weather to a silty clay with a very low permeability to water. The soils that develop on this formation are classified as argillic humic gleysoils (humic gleysols in the WRB System (FAO, 2015)). Overlying the Atherfield Clay is the Hythe Formation, which consists of coarse, porous, non-calcareous sandstones which weather to very acidic humo-ferric podzols (orthic podzols in the WRB System) FAO (2015). The catchment lies south of the glacial limit for any of the Pleistocene glaciations, hence the soils are likely to be older, more weathered, and capable of absorbing more sulphate compared to most UK soils, a situation similar to that found in the USA (e.g. Robison et al., 2013). The vegetation of the area is mixed coniferous-deciduous forest. Trees cover about 89% of the catchment, the main species being Scots pine (*Pinus sylvestris* L.); oak (*Quercus robur* L.) and birch (*Betula pendula* Roth). There are occasional trees of other species, notably a beech (*Fagus sylvatica* L.) plantation at the N. end of the catchment, and European alder (*Alnus glutinosa* L. Gaertn.) in wetland areas. On the basis of annual ring counts, most trees date from about 1920, indicating that any large trees formerly present were felled during the 1914–18 war, a common fate for British trees. The area was then left to recover spontaneously, so the trees are self-sown, giving an open canopy structure. Ground vegetation is overwhelmingly dominated by bracken (*Pteridium aquilinum* (L) Kuhn), which suppresses other ground cover. There were few changes in vegetation over the three study periods: the trees grew larger but growth rates for mature trees on these infertile soils are slow.

The catchment is drained by a small stream (the Tillingbourne) which is seasonal (drying in summer) in its upper reaches, but perennial at the catchment exit where it is sustained by inputs from groundwater.

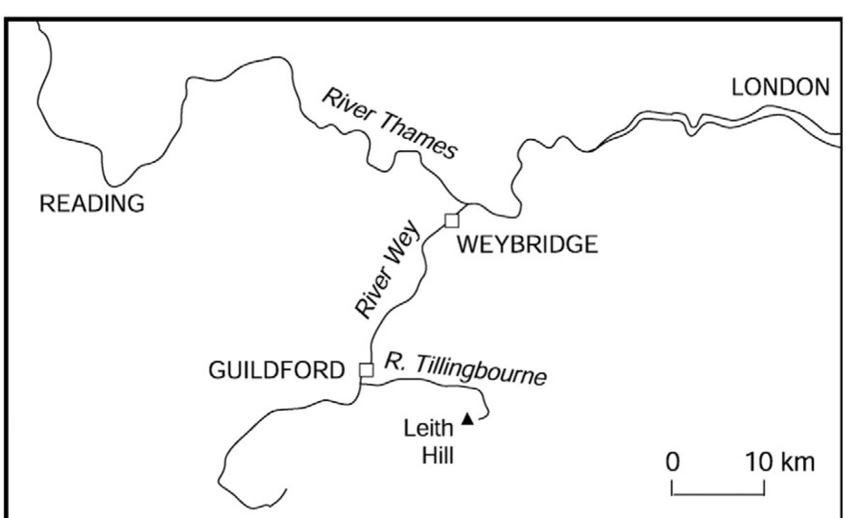


Fig. 1. Situation of the Tillingbourne Catchment (triangle) in the UK.