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Comparison of different critical load approaches for assessing streamwater acid-sensitivity to broadleaf woodland expansion

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ABSTRACT

Due to its potential adverse effects on freshwater acidification, risk assessments of the impacts of forest expansion on surface waters are required. The critical load methodology is the standard way of assessing these risks and the two most widely used models are the Steady-State Water Chemistry (SSWC) and First-order Acidity Balance (FAB) models. In the UK the recommended risk assessment procedure for assessing the impact of forest expansion on freshwater acidification uses the SSWC model, whilst the FAB model is used for guiding emission policy. This study compared the two models for assessing the sensitivity of streamwater to acidification in 14 catchments with different proportions of broadleaf woodland cover in acid-sensitive areas in the UK. Both models predicted the exceedance of streamwater critical loads in the same catchments, but the magnitudes of exceedance varied due to the different treatment of nitrogen processes. The FAB model failed to account for high nitrogen leaching to streamwater, attributed to nitrogen deposition and/or fixation of nitrogen by alder trees in some study catchments, while both models underestimated the influence of high seasalt deposition. Critical load exceedance in most catchments was not sensitive to the use of different acid neutralising capacity thresholds or runoff estimates, probably due to the large difference between critical load values and acidic deposition loadings. However, the assessments were more sensitive to differences in calculation procedure in catchments where nitrogen deposition was similar to the availability of base cations from weathering and/or where critical load exceedance values were <1 keq H^+ ha^{-1} yr^{-1}. Critical load exceedance values from both models agreed with assessments of acid-sensitivity based on indicator macroinvertebrates sampled from the study catchments. Thus the methodology currently used in the UK appears to be robust for assessing the risk of broadleaf woodland expansion on surface water acidification and ecological status.

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1. Introduction

Freshwater acidification resulting from deposition of atmospheric sulphur (S) and nitrogen (N) has resulted in adverse impacts on aquatic ecology worldwide, most notably the depletion of salmonid fish (e.g. Driscoll et al., 2001; Stevens et al., 1997). The impact of freshwater acidification has been extensive in the UK, affecting thousands of km of river length in the 1980s and 1990s, resulting in estimated annual economic losses in fisheries of millions of pounds (Jenkins and Ferrier, 2000). To address these problems international agreements are in place to reduce atmospheric emissions of S and N. The critical load concept has been widely accepted as the basis for the development of air pollution control strategies in Europe (Gregor et al., 2001), and has been used for assessing the sensitivity of freshwaters to acidification in 24 countries in Europe and North America (UBA, 2004). The critical load of acidity for surface waters is "the highest deposition of acidifying compounds that will not cause chemical changes leading to long term harmful effects on ecosystem structure and function" (Nilsson and Grennfelt, 1988) and is calculated as the pre-acidification availability of base cations, estimated from present-day water chemistry, minus a required level of buffering or acid neutralising capacity (ANC) to maintain suitable conditions. An appropriate ANC threshold is selected to maintain acceptable conditions for specified aquatic organisms (usually fish). Surface waters that receive acid deposition greater than the critical load are termed "exceeded" and at risk of biological damage. Although emission reduction has led to significant chemical recovery in previously acidified waters (Davies et al., 2005), biological recovery has been more limited (Monteith et al., 2005). Acidification is still a serious issue in parts of the UK; e.g. 22% of the rivers in the Wales/England cross-border Dee River Basin District are at risk of failing to achieve good ecological status by 2015 due to acidification (Environment Agency, 2008).

Since one of the contributory factors to acidification is forestry, the Forests & Water Guidelines produced by the Forestry Commission (2003) require assessment of the risk of new planting or restocking of

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existing forests enhancing acidification in acid-sensitive catchments in the UK. The Forestry Commission has adopted the Steady-State Water Chemistry (SSWC) model (Henriksen et al., 1986) to assess freshwater acid-sensitivity, whilst the First-order Acidity Balance (FAB) model (Posch et al., 1997) is used in the UK to calculate freshwater critical loads to guide emission policy (UK National Focal Centre, 2004). The SSWC model was initially developed to address the impact of S deposition and is the simplest such model, requiring water chemistry measurements and annual runoff (usually estimated from annual rainfall since runoff data are rarely available) to calculate critical loads. The FAB model attempts to model explicitly the fate of incoming N deposition and leaching to waters and requires additional catchment data. In the UK different ANC thresholds to protect target sensitive freshwater organisms have been selected. The Forests & Water Guidelines have adopted an ANC threshold of 0 μeq l^{-1} whilst the National Focal Centre normally uses an ANC value of 20 μeq l^{-1}, although 0 μeq l^{-1} is applied if site-specific data suggest that the pre-industrial value was lower (UK National Focal Centre, 2003).

Due to differences in formulation and data requirements, assessments of freshwater acid-sensitivity may be affected by the choice of model and there is a need to examine the robustness of the Forestry Commission approach. This study focused on broadleaf woodland expansion which is encouraged by current policies in the UK but which may still exert a significant impact on the most acid-sensitive freshwaters (Alexander and Cresser, 1995). It compared the suitability of the SSWC and FAB models for assessing surface water acidification within acid-sensitive areas of the UK. The effects on calculated critical loads and exceedance values of different ANC thresholds and runoff estimates were also investigated as the latter reflect changes in catchment water yield related to woodland expansion and are thus particularly relevant to the Forestry Commission approach. Finally, since the purpose of critical load assessments is to protect freshwater ecosystems from acidification, the outputs from both models were compared with the current status of macroinvertebrate populations as an indicator of freshwater acidity status.

2. Materials and methods

2.1. Study catchments

Fourteen study catchments with varying proportions of broadleaf woodland cover and no other confounding land uses were selected from across the main acid-sensitive areas of the UK as defined by falling either within 10 km × 10 km critical load exceedance squares or adjacent squares. Exceedance squares are those in which modelled atmospheric deposition of non-marine S and N for 1995–1997 exceeded the critical load calculated with the SSWC model from the chemical analysis of water samples from the most sensitive water body, usually a lake, within each square (Curtis and Simpson, 2001). Due to the relatively coarse spatial resolution of this approach waters in squares adjacent to those in which critical loads are exceeded are also considered at risk in the Forests & Water Guidelines. The catchments ranged from Glen Arnisdale in north Scotland, Loch Katrine in central Scotland and Ullswater in north-west England to Yarner Wood and Narrator Brook (part of the UK Acid Waters Monitoring Network (AWMN, Evans et al., 2000)) in Devon, south-west England. The catchment characteristics are summarised in Table 1 and detailed in Gagkas (2007). Catchment geologies and

Table 1

Characteristics of the study catchments in Glen Arnisdale (GA), Loch Katrine (LK), Ullswater (UL), Yarner Wood (YAR) and Narrator Brook (NAR). Broadleaf woodland cover calculated from the Forestry Commission (2001), catchment geology from the British Geological Survey (1995) and percentage cover of soil types from NSRI (1984) and MISR (1981). Tree species: downy birch (*Betula pubescens*), alder (*Alnus* spp.), and sessile oak (*Quercus petraea*). Main soil types: PZ = podzols, GL = gleysols, and LP = leptosols (after IUSS Working Group WRB, 2006). Critical load exceedance is from the 1995–97 dataset for UK freshwaters (see text for explanation).

Area	Geology of area	Main soil types of area	Catchment	Latitude (°N), longitude (°E) of catchment outlet	Land cover	Catchment area (ha)	Mean (min–max) altitude (m)	Mean slope (°)	Cover of main soils (%)	Critical load exceedance class (keq H^+ ha^{-1} yr^{-1})
Glen Arnisdale, north-west Scotland	Schists and gneisses of the Moine group	Histic podzols, histic gleysols, and sapric histosols	GA1	57.123, −5.506	27% natural downy birch	66.0	444 (84–640)	29	PZ (53) GL (17)	0.0–0.2
			GA2	57.124, −5.516	25% natural downy birch	16.9	428 (53–611)	28	PZ (55) GL (19)	0.0–0.2
			GA3	57.123, −5.516	20% natural downy birch	53.5	338 (40–600)	29	PZ (37) GL (31)	0.0–0.2
			GACON	57.123, −5.528	Acid grassland, blanket bog	35.6	272 (9–489)	26	PZ (33) GL (32)	0.0–0.2
Loch Katrine, southern Highlands, Scotland	Dalradian schists, grits and shales	Osteinic albic folic and histic podzols	LK1	56.272, −4.597	29% natural downy birch	103	412 (128–683)	26	PZ (90) GL (2)	0.5–1.0
			LK2	56.289, −4.626	16% natural downy birch	132	461 (139–763)	23	PZ (81) GL (1)	0.5–1.0
			LK3	56.277, −4.604	20% natural downy birch	20.9	367 (185–556)	24	PZ (93) GL (7)	0.5–1.0
			LK4	56.292, −4.644	10% natural downy birch	39.6	502 (182–726)	26	PZ (89) GL (4)	0.5–1.0
			LKCON	56.284, −4.616	Purple moor grass, fen	47.6	407 (134–681)	24	PZ (91) GL (5)	0.5–1.0
Ullswater, north-west England	Ordovician slates and silicic tuffs	Histic gleysols and leptosols	UL1	54.595, −2.823	54% mature, semi-natural alder	8.56	306 (204–401)	9	GL (100)	Non-exceeded adjacent square
			UL2	54.595, −2.831	79% mature, semi-natural alder	17.0	265 (176–386)	10	GL (97) LP (3)	Non-exceeded adjacent square
			ULCON	54.589, −2.834	Wet heath, fen	8.99	313 (187–462)	22	LP (70) PZ (15) GL (15)	Non-exceeded adjacent square
Devon, south-west England	Upper Carboniferous sandstones and slates	Histic stagnic podzols and haplic dystric cambisols	YAR	49.967, −3.696	50% semi-natural/ sessile oak	134	272 (108–411)	11	PZ (100)	0.2–0.5
	Granite		NAR	49.959, −3.979	2% oak woodland; acid grassland, blanket bog	255	366 (255–456)	18	PZ (67) GL (33)	0.2–0.5

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