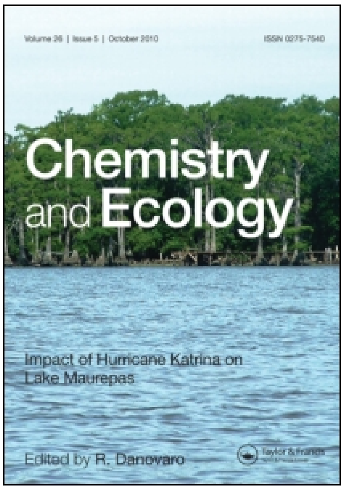

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EVIDENCE FOR pH INSENSITIVITY IN SOME INSECTS INHABITING PEAT POOLS IN THE LOCH FLEET CATCHMENT

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The impact of liming on the insects associated with peat pools was studied in the Loch Fleet catchment in 1991 and 1992. Fifty-six taxa were identified from 121 timed samples. Despite the raised pH associated with liming in 1986, the population densities of Odonata, Hemiptera and Coleoptera appeared to be unaffected when compared with those of untreated peat pools in the same area. The study demonstrated the existence of two main types of community, that of the steep-sided edges of pools, dominated by odonate nymphs and large species of beetles, and that of the shallower pools, dominated by *Hydroporus* species (Col., Dytiscidae).

KEY WORDS: Liming, pH insensitivity, peat pools, Odonata, Hemiptera, Coleoptera, multivariate analysis

INTRODUCTION

Loch Fleet (National Grid Reference NX 559699) is a small loch on the granite massif of the Fell of Fleet. It is an area of high acid deposition (United Kingdom Acid Waters Review Group, 1988). The loch lost its trout fishery in the early 1970's. The most effective of the catchment treatments designed to restore the fishery was the application of lime to a peat bog, the treatment of which maintained a high pH in the main feeder stream for the loch. This stream was the main spawning area for the newly established trout (Howells and Dalziel, 1992; Howells, Dalziel and Turnpenny, 1992). The success of this method of catchment treatment has raised concern about the impact of liming on bogs and their fauna and flora. This study concerns a retrospective attempt to evaluate the effects of liming on the insect fauna of peat pools in the area.

METHODS

Lime was applied in April 1986 as 106 tonnes of dust in spot treatments above Loch Fleet on the Fell of Fleet. Application was localised in an area of watershed mire (NX 561706) containing large and small peat pools. The treatment killed *Sphagnum* moss, in particular *S. papillosum* Lindb., where directly exposed to limed water, but most of the vegetation, including the *Sphagnum* above the usual level of standing water, had survived three years after liming (Clymo *et al.*, 1992). In 1992, it was still possible to recognise the deposits left by some sacks of lime and many of the pool edges produced a milky suspension of lime dust when disturbed, with water pH as high as 8.5. It has been estimated (Howells and Dalziel, 1994) that about two-thirds of the lime remained in the bog in February 1994.

With the help of aerial survey photographs taken of the Fell of Fleet in 1981, a suite of untreated peat pools was identified in 1990 to be compared with the treated area. Methods of sampling invertebrates were also compared in 1990. Timed sampling was found to be more practicable than area/volume sampling (attempted by extraction of the material from large plastic cylinders driven into the bottoms of the pools). A 30-second sample with a 1 mm mesh D-frame pond net produced sufficient data for analysis of the common species, whereas one minute samples were too large for small peat pools and flushes, took too long to extract and reduced replication. In August 1991 invertebrates were sampled by 48 half minute samples from pools and flushes in the limed bog (sector VII) and from the areas unaffected by liming. Identification was achieved mainly in the field but voucher samples of invertebrates other than beetles were taken to the laboratory. Nymphal corixid bugs and larval beetles were identified to tribe and were returned alive to the pools. Sampling site descriptions included the availability of open water above the peat or surface covering of *Sphagnum*, and its depth from "shallow" (< 5 cm) to "deep" (> 30 cm).

Preliminary analysis revealed the substantial difference in the faunas of shallow and deep pools. A further 73 samples were taken in August and September 1992, with more effort directed to the sampling of the shallow pools under-recorded in 1991. Some of these were so full of organic debris that netting was extremely difficult. Corixid adults caught in 1992 were bulked into groups from limed and unlimed areas and returned to the laboratory for identification. Nomenclature follows Miller (1987) for Odonata, Savage (1989) for Hemiptera and Friday (1988) for Coleoptera.

The pH of water samples from each pool was measured using a Jencons portable pH meter calibrated on each day of use. The geometric mean pH for limed pools was 6.7 in 1991 and 5.6 in 1992, the mean for unlimed pools being 4.0 in both years.

Statistical analysis was performed on the counts for each taxon using the raw data, also the data converted to log $(n + 1)$, and where appropriate, by undertaking analysis of variance for the pooled data, partitioning the variance between years. Multivariate analysis for each sample was undertaken using Detrended Correspondence Analysis (DECORANA-Hill, 1979) of raw counts. The two sub-sets of data indicated by multivariate analysis were re-analysed for individual taxa.

RESULTS

Forty-three taxa were identified to species within each sample in 1991 (Table 1) with a further three groups of larval Coleoptera and a single category for corixids. Thirty-one taxa were identified to species in the 1992 samples (Table II), including four species not detected in 1991. There were no significant differences in the counts of individuals belonging to 51 invertebrate taxa (Odonata, Hemiptera and Coleoptera) between the limed and unlimed pools.

In 1992, 201 individuals of adult corixids were identified to six species from samples bulked into limed and unlimed groups: *Corixa punctata* (Illiger) *Callicorixa wollastoni*

Table I Mean densities of taxa in 30-second net samples from limed and unlimed pools in 1991.

	Steep-edged pools		*Shallow pools*		*Total*	
Number of samples→	*Limed* *22*	*Unlimed* *16*	*Limed* *4*	*Unlimed* *6*	*Limed* *26*	*Unlimed* *22*
ODONATA						
Pyrrhosoma nymphula	0.7	0.5	0	0	0.6	0.3
Sympetrum danae	0.4	0.2	0	0	0.3	0.1
Aeshna juncea	8.7	4.6	0	0	7.3	2.9
HEMIPTERA						
corixids	18.3	7.5	2.0	6.3	15.8	6.5
Notonecta glauca	3.2	1.5	0	0	2.7	1.0
Velia caprai	0.1	0	0	0	0.1	0
Gerris lacustris	0.1	0.2	0.8	0.3	0.2	0.2
COLEOPTERA						
Haliplus fulvus	0.1	0.1	0	0	0.04	0.1
Haliplus lineatocollis	0.1	0	0	0	0.1	0
Haliplus ruficollis	0.4	0.6	0.3	0	0.3	0.4
Hygrotus inaequalis	0	0.1	0	0	0	0.1
Hydroporus erythrocephalus	0.1	0	0	0	0.1	0
Hydroporus gyllenhalii	0.2	0.6	1.5	3.2	0.4	1.2
Hydroporus incognitus	0.1	0	0.3	0.2	0.1	0.1
Hydroporus longicornis	0	0.1	0	0	0	0.1
Hydroporus melanarius	0	0.1	0.5	0	0.1	0.1
Hydroporus memnonius	0	0	0.3	0	0.04	0
Hydroporus morio	0.1	0.3	6.8	11.7	1.1	3.4
Hydroporus obscurus	0.8	1.1	0	0.5	0.7	0.8
Hydroporus palustris	0.1	0.1	0	0	0.04	0.1
Hydroporus pubescens	1.2	0.9	9.3	17.7	2.5	5.4
Hydroporus tristis	0.8	0.2	0	1.5	0.7	0.5
Agabus arcticus	0.7	2.6	0	0	0.6	1.6
Agabus bipustulatus	1.6	1.9	1.3	3.2	1.5	2.0
Agabus congener	0.1	0	0	0.3	0.04	0.1
Agabus guttatus	0	0.2	0	0	0	0.1
Agabus nebulosus	0.1	0	0	0	0.1	0
Agabus paludosus	0.1	0	0	0	0.04	0
Agabus sturmii	0.8	0.1	0	0	0.7	0.1
Ilybius aenescens	2.4	2.4	0	1.2	2.0	1.8
Ilybius fuliginosus	0.1	0	0	0	0.04	0
Rhantus suturellus	0.1	0	0.3	0	0.2	0
Colymbetes fuscus	0	0.1	0	0.3	0	0.2
colymbetine larvae	0.5	0.1	0	0.8	0.4	0.3
Acilius sulcatus	0.1	0.1	0	0	0.4	0.1
dytiscine larvae	0.1	0	0	0	0.1	0
Gyrinus minutus	0.1	0	0	0	0.1	0
G. substriatus	0.9	0.1	0	0	0.7	0.1
gyrinid larvae	0.2	0.1	0	0	0.2	0.1
Helophorus aequalis	0	0	0.3	0	0.04	0
H. flavipes	0	0.1	2.8	1.5	0.4	0.5
Hydrobius fuscipes	0.1	0	0	0.2	0.04	0.1
Anacaena globulus	0.2	0.4	7.0	0.3	1.3	0.3
A. lutescens	0.1	0	0	0.2	0.1	0.1
Enochrus affinis	0	0.1	0	0	0	0.1
E. fuscipennis	0.2	0	0.3	0	0.2	0
Limnebius truncatellus	0.2	0	0	0	0.2	0

Table II Mean densities of taxa in 30-second net samples from limed and unlimed pools in 1992.

	Steep-edged pools		*Shallow pools*		*Total*	
Limed	*Unlimed*	*Limed*	*Unlimed*	*Limed*	*Unlimed*	
Number of samples→	*22*	*18*	*10*	*23*	*32*	*41*
ODONATA						
Pyrrhosoma nymphula	0.4	1.4	0.1	0	0.3	0.6
Sympetrum danae	0.1	0	0	0	0.06	0
Aeshna juncea	1.64	9.1	0	0	1.1	4.0
HEMIPTERA						
corixids	7.1	8.6	0.3	6.3	5.0	4.1
Notonecta glauca	0.5	0.5	0	0	0.3	0.2
Gerris lacustris	0.1	0	0	0	0.06	0
COLEOPTERA						
Hydroporus erythrocephalus	0	0	0	0.04	0	0.02
H. gyllenhalii	0	0.2	0.5	2.4	0.2	1.5
H. morio	0	0	0.7	4.8	0.2	2.7
H. obscurus	0	0	0.1	0.6	0.03	0.3
H. planus	0.05	0	0	0	0.03	0
H. pubescens	0	0.2	2.3	5.2	0.7	3.5
H. tristis	0	0	0.1	0.3	0.03	0.2
Agabus arcticus	0.05	0.3	0	0	0.03	0.2
A. bipustulatus	0.4	0.8	0.4	1.3	4.4	1.1
A. congener	0	0	0	0.04	0	0.02
A. nebulosus	0.1	0	0	0	0.06	0
Ilybius aenescens	0.2	0.1	0	0.04	0.1	0.07
Rhantus suturellus	0	0	0	0.04	0	0.02
Colymbetes fuscus	0	0.2	0.5	0	0.2	0.07
colymbetine larvae	0.2	1.0	1.5	0.7	0.6	0.9
Gyrinus substriatus	0	0.2	0	0	0	0.1
Helophorus brevipalpis	0	0	0	0.04	0	0.02
H. flavipes	0	0.06	2.7	5.3	0.8	3.0
H. grandis	0	0.06	0	0	0	0.02
Hydrobius fuscipes	0	0	0.1	0	0.03	0
Anacaena globulus	0.05	0	0.2	0.9	0.09	0.5
A. lutescens	0	0.2	0	0	0	0.07
Enochrus affinis	0	0	0	0.3	0	0.2
E. fuscipennis	0	0	0.3	0	0.09	0
Limnebius truncatellus	0	0	1.9	0	0.6	0

(Douglas and Scott), *Hesperocorixa castanea* (Thomson), *Sigara nigrolineata* (Fieber) and *S. scotti* (Douglas & Scott). More specimens of the commonest species, *C. wollastoni* and *H. castanea*, were found in limed pools than in the untreated pools, but there were no significant differences, as measured by a χ^2 test.

The first axis of DECORANA was dominated by small beetles associated with shallow and temporary water at one extremity and by the larger insects of permanent, deeper pools at the other. The ordination of species on the second axis reflected the greater number of shallow pools sampled in 1992 than in 1991, and the third axis had at one extremity those species characteristic of slow-flowing water (*Velia caprai* Tamanini, *Hydroporus longicornis* Sharp and *Agabus guttatus* (Paykull)). None of the axes had those species associated typically with acid water at one extremity and those of base-rich or neutral water at the other.

A plot of DECORANA site scores for axis 1 and axis 2 indicated a structure based on a tight cluster of sites associated with steep-edged, deeper pools and a more diffuse cluster based on samples from shallow parts of pools and gullies. All of the samples from the deeper sites (> 30 cm open water) had axis 1 scores less than 262 and all of the shallow sites (< 5 cm open water) had scores exceeding 270. More shallow sites were sampled in 1992 than in 1991, and they showed greater variation than in 1991 (Figure 1). Limed and unlimed site lists did not form discrete groups.

Statistical procedures for individual taxa were repeated using separate data sets for shallow pools and steep-sided pools. As with the full data set, there were no significant differences between samples from limed and unlimed sites in the data sub-sets.

DISCUSSION

Over 3,000 individuals of at least 54 species were sampled in 1991 and 1992 from pristine peat pools and from those clearly exposed to the most severe effects of liming 5-6 years earlier. It proved impossible to demonstrate significant differences between population densities of limed and unlimed pools.

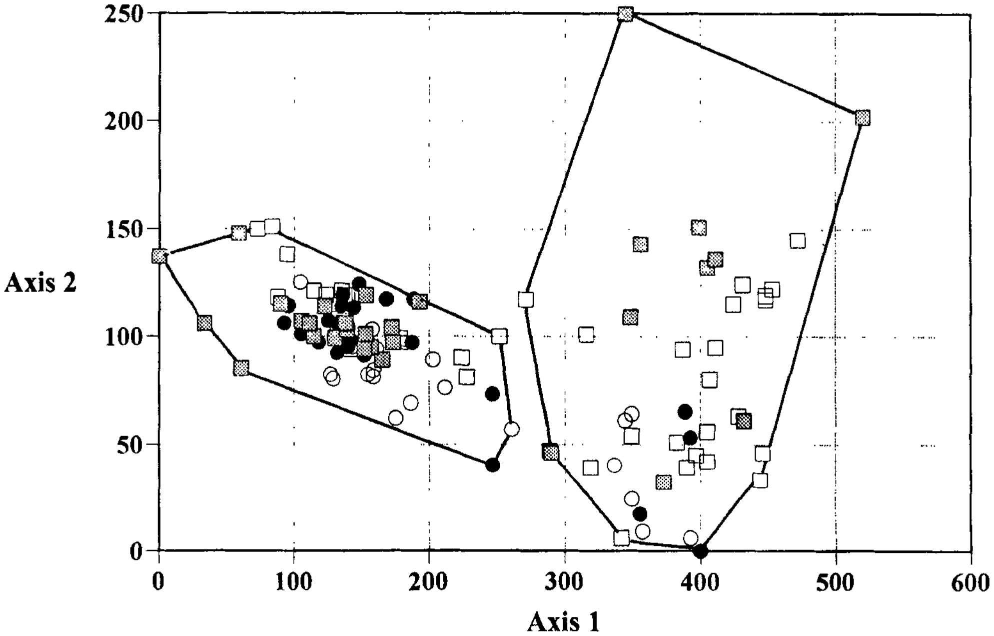

Figure 1 Plot of axis 1 and axis 2 DECORANA site scores for the invertebrate assemblages associated with limed and unlimed pools in 1991 and 1992. The polygons separate the faunas of deep (left) and shallow pools (right). Samples from 1991 are circles and those from 1992 are squares. Shaded symbols indicate pools affected by lime and clear symbols are for sites unaffected by lime.

The abundance of immature stages indicated that breeding was continuing to take place within the limed pools. In 1991 there were 42 individuals per sample in the limed pools and 31 in the unlimed pools. The situation was reversed in 1992, with 11 in limed pools and 23 in unlimed pools. Such variation is more likely to be associated with the seasonal fluctuations in productivity rather than the impact of liming. Regular recolonisation of treated pools from the surrounding areas is an unlikely alternative explanation for sustained high populations at this altitude, with its cool climate and brief growing season.

This study demonstrates an interesting phenomenon, the fact that many of the commonest taxa, generally considered to be acidophilous, continue to breed successfully in calcium-rich habitats. The association of such species with acid water is therefore not because they are "acid-loving". With boreal species such as *Hydroporus morio* and *Agabus arcticus*, an association with acid water may simply reflect the occurrence of acid waters under the cool conditions that such species tolerate better than others. Other possibilities are a tolerance of poor nutrient status and dependence on a soft, organic substratum. The simplest explanation of the survival of such so-called acidophiles through an episode of nutrient enrichment is that less tolerant species are not immediately available to compete with them. A few "ruderal" species have been detected, i.e. pioneer species that would not normally be associated with upland peat pools, e.g. *Hydroporus planus* and *Agabus nebulosus*, and it is possible that these might increase in numbers if liming was to be repeated. The nearest breeding centres for such potential colonists are lowland, mainly coastal, pools and marshes. Such centres might reasonably be considered well within a day's dispersal flight by such species, all of which have strong flight capacity. If treatment of a bog system is considered to be the best way of sustaining a fishery, retention of the dominant bog fauna would best be achieved by alternation of liming between several subsections of a bog, rather than by repeated treatment of the same section.

This study emphasised the substantial difference between the invertebrate assemblages of two main types of bog pool, a difference that does not appear to have been emphasised previously for European bogs. The commonest species of the shallow pools are beetles about 3–4 mm long (mainly small diving beetles in the genus *Hydroporus*), whereas deeper pools are dominated by odonate nymphs, Heteroptera and large diving beetles in the genera *Agabus* and *Ilybius* (Figure 2). Larson and House (1990) identified two principal communities associated with Newfoundland bog pools. Oligochaetes, beetles and mosquitoes dominated small, astatic pools whereas odonates, chironomids and larger beetles dominated in large, stable pools. Water level stability was postulated as the main factor determining this community structure. It was noted that odonate nymphs could exert a powerful predation pressure within large pools, to the extent that they might dictate the abundance and distribution of prey taxa within bog pool systems. There are strong parallels between the observations at Loch Fleet and those in Newfoundland; the survival of the larger predatory species in limed pools indicates that community structures will be largely unaffected by what at first appears to be an extreme form of intervention treatment.

The effects of acidification on invertebrate faunas of streams and lakes are well known (Sutcliffe and Hildrew, 1989; Økland and Økland, 1986), and recovery from acidification, either through alleviation of the deposition burden or by liming, has also

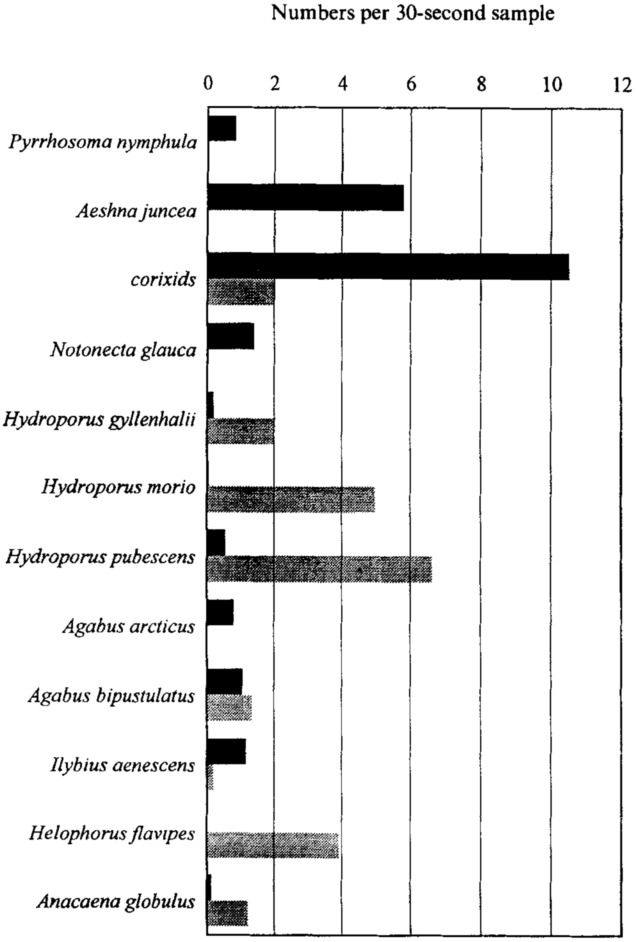

Figure 2 Densities of taxa exceeding 0.5 individuals per 30-second sample in samples combined for deep pools (dark shaded bars) and shallow pools (paler shaded bars).

been studied, particularly in Norway (Raddum and Fjellheim, 1994). Species most sensitive to acidification include mayflies (Ephemeroptera), stoneflies (Plecoptera), caddis flies (Trichoptera), macrocrustaceans (crayfish, *Gammarus* and *Asellus* species) and gastropod molluscs. Corresponding increases in the numbers of such invertebrates generally occur when stream sites are limed. Mayfly populations become re-established in lakes, despite increased fish predation. The most striking effect of liming lakes has been a strong decrease in the density of benthic animals, in particular chironomid midge larvae (Raddum and Fjellheim, 1994). The causes of these changes are usually grouped into direct (primary) and indirect (secondary) effects, the former mainly associated with sensitivity to the concentration of H^+ ions and toxic metals, and the latter with predator prey interactions, in particular the influence of fish as the principal predators.

It appears that no comparable work has been undertaken on the invertebrate fauna of the smaller water bodies associated with peatlands, though loss of *Sphagnum* species and other floristic changes have been identified (Fry and Cooke, 1984). In particular, the effects of acid deposition are unknown. Changes are presumed to be minimal because acidification is acting on a naturally impoverished fauna composed of species tolerant of the direct effects of acidification. Such species are not subject to the major indirect effect in other waters, i.e. fish predation, because fish cannot tolerate the conditions of peat pools. Inevitably, given that there is no evidence of anything from which to recover, there is no work recording recovery following reduced acid deposition. The freshwater resource associated with bog pools and similar small water bodies in Scotland is estimated at not less than 50,000 hectares (R. Lindsay, pers. comm.). Despite this magnitude, the peat pool complex, particularly the tension pool systems of blanket bogs, is fragile in that such systems are easily damaged by drainage (Ratcliffe and Oswald, 1988). It should be pointed out that Britain has approximately 13 per cent of the world's total resource of bogs of the blanket type (Ratcliffe and Oswald, 1988). The presumption that such systems are robust in regard to acidification appears to have been made by default; the present study at least indicates that a quite severe change in ion balance has little effect on the major predator complexes.

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