RUN-OFF FERTILIZER NITRATE ON LUNDY AND ITS POTENTIAL ECOLOGICAL CONSEQUENCES

By

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Nitrate fertilisers have been applied to fields in the south of Lundy since 1991. The island's ponds and streams and their adjacent soils were sampled in 1996 for nitrate and other characters in order to detect whether leaching from these agricultural pastures was affecting areas of importance for conservation. The study was carried out in January, after the period when most of the run-off from the 1995 fertiliser applications is likely to have occurred. Stream nitrate levels were found to be highly variable, and related to the presence or absence of fertiliser application, rather than geology. The streams draining fertilised areas were also less acid. Dissolved oxygen in the ponds was not related to nitrate application, while pH reflected geology. Increased nitrate is known to increase plant biomass, but diminish species diversity in grasslands. Continued use of fertilisers on the island could therefore result in local floristic changes in the grasslands of the south-east of the island, with potential consequences for the uncommon Balm-leaved Figwort (*Scrophularia scorodonia*) and the endemic Lundy Cabbage (*Coincya wrightii*).

INTRODUCTION

Lundy is of particular conservation interest because of its unusual flora, which includes the endemic Lundy Cabbage and other plants not found in abundance on mainland Britain (Perring & Walters 1962). Consequently, much of the island has been designated as a Site of Special Scientific Interest, although the improved pasture in the south of the island is excluded from the SSSI.

When the amount of nitrogen fertiliser applied to fields exceeds the rate of growth and uptake of vegetation any residual nitrogen is leached away. Permanent pastures are efficient at nitrogren uptake compared to arable systems (often holding around 75% of that applied, Cooke 1970, Tivy 1990), yet permanent grasslands lose some nitrate even without fertilisation. Consequently, nitrate fertilisers are a significant cause of anthropogenic eutrophication and may be particularly problematic when adjacent to sensitive habitats (Tivy 1990). Nitrate leaching is influenced by climate, soil, the amount of fertiliser and the timing of application (Tomlinson 1970). When rainfall is high following application, or the soil is bare, surface run-off occurs. Soluble nitrate also enters the soil with rain water and is leached by the sub-surface run-off. Run-off severity is therefore positively correlated with precipitation, and most nitrogen is lost in winter during a few large flushes following heavy rainfall (Tomlinson 1970).

The effects of nitrogen fertilisation on vegetation have been studies extensively (Grime 1973, Rorison 1971). Fertilisation typically results in increased biomass production, but decreased species diversity. This is because fertilisation allows competitively dominant species to flourish at the expense of other species. Fertilisers can also affect biological communities indirectly. Nitrate can alter tha pH (acidity) of the soil, which alters the response of vegetation to fertiliser application (Rorison 1971) and, in lakes and ponds, nitrate can cause algal blooms. When the algae decompose, dissolved oxygen declines, producing high Biological Oxygen Demands (B.O.D.) and sometimes anoxic conditions that can kill fish and other animals (Haslam 1992).

On Lundy, fertiliser has been applied to permanent grasslands to revitalise heavily over-grazed vegetation (E. Parkes Pers. Comm., 1996). In 1995, ammonium nitrate was applied over the 87 hectares of improved grassland in the south of the island in early April, using two rates of application (87.5 kg N ha^{-1} or 112.5 kg N ha^{-1}). The summer of that year proved exceptional, with a prolonged drought which led to much of the stock being evacuated. This paper describes an investigation of the concentrations of nitrate and other constituents in the streams, ponds and soils of the island during the following winter, and how these are related to areas where fertilisers had been applied. The possible consequences for the vegetation of the island are also discussed.

MATERIALS AND METHODS

Fieldwork was carried out between 12-24 January 1996. Water samples were collected from 16 streams (1-16, Fig. 1) and four pools, one of which was subdivided (P1-P4, Fig 1). Between three and seven water samples were taken along the length of each stream. The amount of dissolved oxygen was measured using a hand-held oxygen-sensitive electrode meter which had been recently calibrated. Within twelve hours of collection, the pH was measured using a hand-held pH meter. Samples from pools were stored at between 12°C and 18°C for five days and their dissolved oxygen content was measured again in order to calculate the Biological Oxygen Demand, based on the depletion of dissolved oxygen in each sample over the period of five days (Hynes 1960). Samples were filtered using Whatman No. 1 medium papers in order to remove debris and stored at approximately 4°C. Subsequently, anionic composition was determined at Leeds University using a standard liquid chromatography method.

Samples of top soil were collected at 23 localities, mainly in the south of the island. Where soils were taken from coombes with streams, the samples were taken at 20 - 50 cms from the edge of the stream. The collected soil was made into a paste with an equal volume of distilled water, allowing the pH to be measured using a hand-held pH meter. The soil pastes were then filtered using Whatman No. 1 medium papers and from the filtrate the nitrate-nitrogen concentrations were estimated using Merckoquant 10 020 nitrate test strips or liquid chromatography.

RESULTS

Streams

Dissolved oxygen in the sixteen streams was high, averaging 69.4% ± SD 8.7 (Table 1). Mean nitrate concentrations ranged from 0.9 mg l^{-1} to 39.2 mg l^{-1}. The mean nitrate from the seven streams draining the fertilised area was 14.8 mg l^{-1} and from the unfertilised area, 1.8 mg l^{-1} (Table 1, Fig 2). The amount of nitrate was significantly higher in the streams that drained the fertilised area than those that did not (Kruskal Wallace comparison of medians H statistic = 6.57, degrees of freedom = 1, probability = <0.025), but was not related to the underlying rocks, which are Eocene granites (I and II) and Devonian slates (Langham 1985), (Kruskal Wallace: H = 1.47, d.f. = 2, p = >0.5).

The pH of the water in the streams became progressively more acidic from south to north, reflecting variation in geology (Kruskal Wallace: H = 92.20, d.f. = 2. p = <0.001, Table 1). It

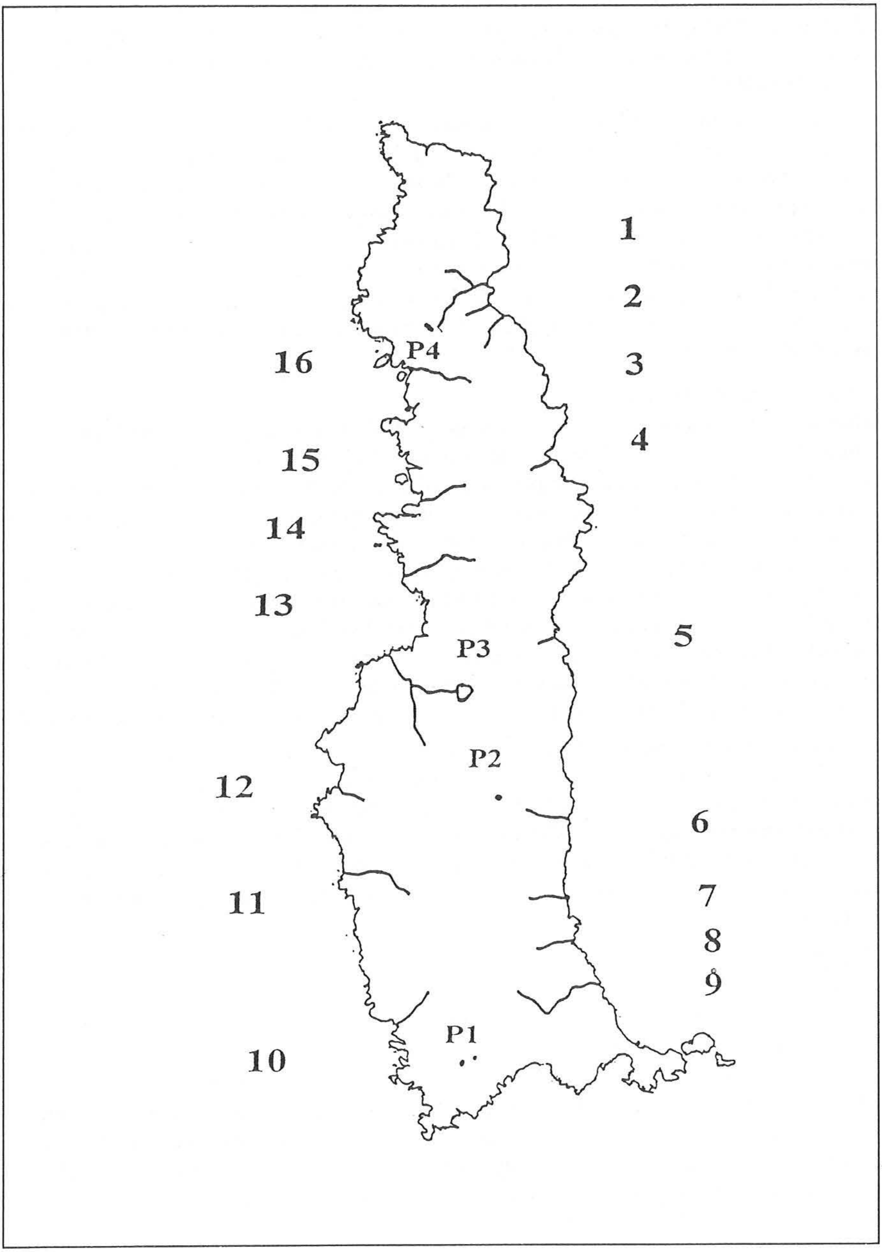

Figure 1. Map of Lundy showing the streams and ponds where water samples were collected.

Table 1: Lundy stream water characteristics in January 1996 (means ±1 SD). The locations of the streams are indicated in Fig. 1.

Stream Number (number of samples)		Location	Dissolved Oxygen	Nitrate (mg l^{-1}) (%)	Phosphate (mg l^{-1})	pH
1	(5)	Gannets' Bay	71.8 ±9.7	0.75 ±0.5	0.00 ±0.0	3.7 ±0.3
2	(3)	Gannets' Bay	53.3 ±6.2	0.90 ±0.9	0.19 ±0.3	5.1 ±0.2
3	(4)	Gannets' Bay	65.8 ±6.8	1.63 ±0.5	0.00 ±0.0	3.8 ±0.2
4	(3)	Threequarter Wall	58.7 ±11.2	3.06 ±0.2	0.00 ±0.0	5.0 ±0.2
5	(2)	Halfway Wall	52.0 ±2.0	1.94 ±0.4	0.00 ±0.0	5.4 ±0.1
6	(7)	Quarter Wall	69.9 ±13.5	9.68 ±2.8	0.00 ±0.0	4.4 ±1.0
7	(4)	St. Helena's Copse	75.0 ±3.7	24.43 ±8.6	0.00 ±0.0	5.3 ±0.5
8	(4)	Broad Coombe	74.4 ±8.7	39.20 ±0.9	0.32 ±0.6	5.2 ±0.5
9	(5)	Millcombe	82.4 ±5.6	16.68 ±8.5	0.44 ±0.4	5.9 ±0.5
10	(5)	South-west Field	67.0 ±14.4	8.51 ±4.0	0.00 ±0.0	5.3 ±0.8
11	(6)	Ackland's Moor	70.0 ±16.2	4.22 ±0.9	0.07 ±0.2	5.2 ±0.5
12	(3)	Ackland's Moor	62.7 ±8.3	1.23 ±1.0	0.00 ±0.0	5.0 ±0.1
13	(5)	Pondsbury	76.8 ±2.6	1.94 ±0.7	0.00 ±0.0	3.8 ±0.5
14	(5)	Middle Park	76.6 ±4.9	2.63 ±0.6	0.00 ±0.0	3.6 ±0.1
15	(5)	Middle Park	79.2 ±4.7	1.68 ±0.3	0.23 ±0.3	4.3 ±0.5
16	(4)	North End	75.3 ±4.6	1.83 ±0.3	0.00 ±0.0	3.6 ±0.0

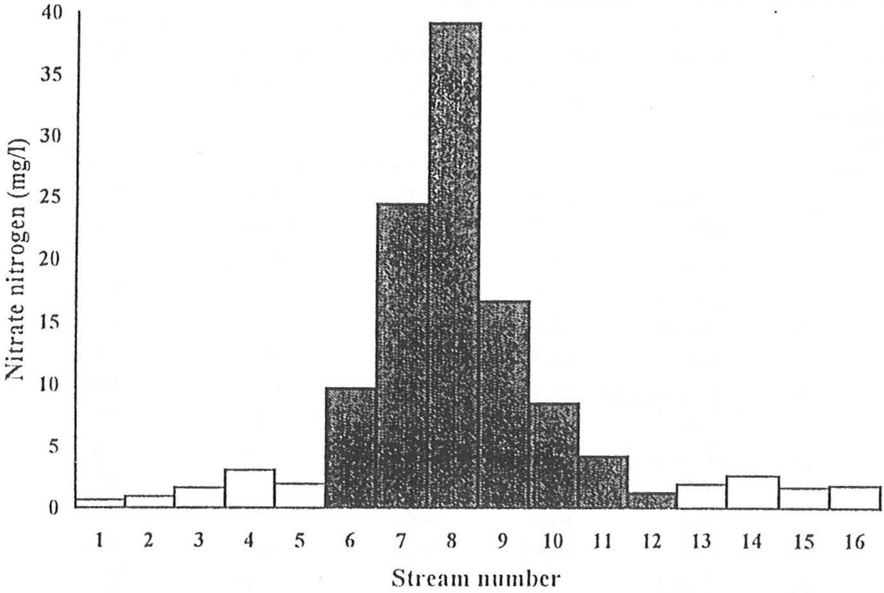

Figure 2. Levels of nitrate nitrogen in the 16 streams indicated in Figure 1. Shaded bars indicate the streams draining the 'improved' fields where fertiliser was applied.

also varied significantly with nitrate application within each geological zone (Granite I, unfertilised and fertilised, mean pH of 4.0 and 5.0 respectively, z test of means, $z = 3.09$, $p = <0.001$. Granite II, unfertilised and fertilised, mean pH of 4.2 and 5.1, z test; $z = 2.20$, $p = <0.01$).

Phosphate levels in the streams were generally low, with eleven of the sixteen containing no detectable amounts (Table 1). However, the concentrations of phosphate in Millcombe was 0.4 mg l^{-1}, considerably higher than elsewhere. It was noted that the lower stretch of this stream was polluted with the effluent from the island's septic tank, which is likely to have contributed both phosphate and nitrate. Phosphate levels in the streams did not differ significantly according to geology (Kruskal Wallace: $H = 2.43$, d.f. = 2, $p = >0.25$), nor fertilisation treatment (Kruskal Wallace: $H = 0.49$, d.f. = 1, $p = >0.1$), which was as expected, given that phosphate-containing fertiliser had not been applied.

Pools

Pool water quality was generally clean or very clean (Hynes 1966) as Biological Oxygen Demand was generally low (Table 2). B.O.D. was not correlated with the amount of nitrate present in the water (Correlation coefficient $r = 0.02$, d.f. = 5, $p = >0.1$). Nonetheless, foaming and scum-formation was noted on the surface of several of the ponds, in particular P1 (the Rocket Pole ponds) and P2 (Quarter Wall Pond). These were also green and 'soupy' due to

Table 2: Lundy pond water characteristics in January 1996. Four distinct ponds were present at Rocket Pole. For locations see Fig. 1.

Pond Number and Name	Location (OS GR)	BOD mg l^{-1} 5 $days^{-1}$	Classification (after Hynes 1966)	Nitrate (mg l^{-1})	pH
Pla Rocket Pole	SS/135.436	0.1	very clean	1.55	6.9
Plb Rocket Pole	SS/135.436	0.6	very clean	8.92	6.6
Plc Rocket Pole	SS/135.436	0.4	very clean	12.80	6.4
Pld Rocket Pole	SS/135.436	1.6	clean	0.78	6.4
P2 Quarter Wall	SS/136.449	2.3	fairly clean	16.35	4.1
P3 Pondsbury	SS/134.455	1.0	very clean	1.80	3.4
P4 North End	SS/132.473	1.3	clean	0.00	3.4

Table 3: Nitrate concentrations and pH of Lundy soil samples in January 1996.

Location (OS GR)	Geological Zone	Nitrate nitrogen (mgl^{-1})	pH
SS/142.442	Granite I	0	4.2
SS/138.442	Granite I	25	5.9
SS/135.437	Granite I	5	5.2
SS/134.438	Granite I	0	4.2
SS/138.444	Granite I	0	5.3
SS/138.448	Granite I	10	6.0
SS/136.449	Granite I	0	4.2
SS/136.449	Granite I	0	4.6
SS/136.449	Granite I	0	3.7
SS/138.447	Granite I	10	4.4
SS/138.445	Granite I	10	3.9
SS/139.443	Granite I	2.7	6.5
SS/139.443	Granite I	1.8	5.9
SS/139.445	Granite I	140.8	2.9
SS/139.444	Granite I	3.7	5.1
SS/139.445	Granite I	5.9	4.5
SS/130.455	Granite II	0	4.3
SS/132.445	Granite II	0	3.6
SS/142.441	Slates	50	5.4
SS/140.440	Slates	5	6.2
SS/139.439	Slates	25	4.9
SS/142.438	Slates	0	8.2
SS/139.441	Slates	10	6.2

large quantities of algae. One of the Quarter Wall ponds was to the north of the wall (the boundary for fertiliser applications) and therefore strictly outside of the fertilisation area. However, due to the relief and drainage of the site, it carried water from the fertilised fields and it too showed frothing and scum. The pH of the ponds varied from weakly to strongly acidic (Table 2).

Soils

The soils north of Quarter Wall contained significantly less nitrate than those to the south (Kruskal Wallace: $H = 6.08$, d.f. $= 1$, $p = <0.025$). The soil pH ranged from an extremely acid 2.9 beneath a large *Rhododendron ponticum L.* (Ericaceae) bush to an alkaline 8.2 on the slates above the Landing Beach (Table 3), and tended to become progressively more acidic from south to north.

DISCUSSION

Our results indicate that the application of fertiliser on Lundy in 1995 led to nitrate enrichment in the streams and immediately adjacent soils of those Sidelands in the south-east of the island which drain the fields. The amounts detected there constitute eutrophication, being greater than 5.0 mg l^{-1}, an accepted maximum for unpolluted grasslands (Cooke 1974). Furthermore, the amounts of nitrate detected in mid-January are almost certainly lower than those which will have occurred in the previous autumn.

Nitrogen from fertiliser applications is highly mobile in the soil and the soils on Lundy are conducive to leaching as they are well-drained, gritty and have a low clay content (English Nature 1994). During the summer, both ammonium and nitrate forms of nitrogen that were applied will have been taken up by the pasture grasses until their growth was impeded by the onset of summer drought. Nitrification would have further contributed to nitrate accumulation in the dry soil in the absence of thorough drainage at that time of year. By late summer, a 'pool' of nitrate will therefore have accumulated in the topsoil. The beginning of drainage flow in late autumn to early winter is a notorious period of the year in temperate climates for nitrate run-off. At this time (rain began at the end of the first week of September, giving about the long-term average for that month. October rainfall was again below average, however - E. Parkes Per. Comm.) leaching from the 'pool' of nitrate will have resulted in a period of unusually high nitrate levels in the streams that drain this area (Walling & Foster 1978).

Denitrification may explain why more nitrate was not detected in the apparently eutrophicated ponds (P1, P2). The nitrate which presumably caused the algal blooms was probably exhausted, and the plants' subsequent decomposition may then have led to temporary deoxygenation. Under those conditions, bacteria reduce any free nitrate, resulting in volatile loss of nitrogen and nitrous oxide gasses through denitrification. However, the BOD of these two ponds in January failed to indicate anaerobic conditions and Galliford (1953) noted algal blooms in 1952 (pre-fertiliser application) on the island. The effects of nitrate application on the ponds is therefore uncertain, and will require further studies during the summer months.

The soil pH range (2.9 - 8.2) was wider than that reported previously (Dawes 1979, Galliford 1953, George & Stone 1980, Long 1993). Our comparisons of soils from fertilised and unfertilised areas within the same geological zones suggests that fertilisation has not resulted in changes in their pH, but was reducing the pH of the streams.

The ecological consequences of the increased nitrate carried by the streams draining the fertilised fields may already be visible, as Key (1995) noted apparent eutrophication-related vegetation changes in the coombes north of Millcombe. Freshwater communities may also be effected. Lundy's acid streams are known to support rich invertebrate communities (Hemsley & Alexander 1992), and are particularly fragile, because the water is weakly buffered against chemical changes (Haslam 1992). Effects upon marine communities are likely to be minimal as nitrate entering the Marine Nature Reserve is diluted and dispersed.

The south-east Sidelands of Lundy support two important plant species - the Balm-leaved figwort (*Scrophularia scorodonia* L. (Scrophulariaceae)) and the Lundy Cabbage (*Coincya wrightii* (O. Schulz) Stace (Brassicaceae)) (Hemsley and Alexander 1992, Perring 1977, Rich 1993). Both are Red Data Book plants and the latter is one of Britain's few endemic species.

S. scorodonia is described as being a species that is found in damp places in species-rich grasslands or low scrub (Hemsley & Alexander 1992). It is commonly associated with nitrophilous species such as *Urtica dioica* L. (Urticaceae), *Rubus fruticosa* L. agg. (Rosaceae) and *Dactylis flomerate* L. (Poaceae) (Meredith 1994) implying that it is a competitive dominant, favoured by fertile soils. However, nitrate tends to favour grasses at the expense of herbaceous plants (Grime 1973a, Rorison 1971) and preliminary experimental work with *S. scorodonia* and *Poa pratensis* L. (Poaceae) indicates that fertilisation with nitrate may increase competition for light and lead to the exclusion of immature *S. scorodonia* by grasses (S. Richardson unpublished). *S. scorodonia* also requires disturbed vegetation (Meredith 1994), which was not considered in these laboratory experiments, and the significance of nitrogen enrichment for this plant remains uncertain.

C. wrightii favours distrubed ground, steep slopes and cliffs. Dominance by grasses and other nitrogen-favoured species under these conditions would not be expected even with nitrate fertilisation and *C. wrightii* therefore seems less likely to be effected than *S. scorodonia*. However, near stream 9 (Millcombe), where *C. wrightii* is abundant, an increased source of available nitrogen has apparently favoured the growth of nettles and brambles. The cabbage population in this area could therefore be threatened in the long term. Sewage, as well as fertiliser run-off is likely to be involved here, however, and this area is outside the current boundary of the S.S.S.I.

As much as 400 kg N ha^{-1} can sometimes be applied to permanent grassland without significant quantities of nitrate being lost (Addiscott *et al* 1991), but grasslands vary in their ability to utilise this resource. Furthermore the drought of 1995 severely reduced plant growth and nitrate take up on Lundy, with the effects we have noted. Unfortunately, drought years cannot be predicted in advance, and the consequences were potentially damaging to the Sidelands. In 1996, stocking densitites were reduced, lowering the need for fertilisers, and only farm manure was spread on the fields (E. Parkes, Pers. Comm.). Re-stocking to 1995 densities is not envisaged in the next few years, and so the problems seem that year are not likely to be repeated (H. Thomas, Pers. Comm.). However, if extensive fertiliser treatments do have to be applied at some point in the future, then protocols that help to reduce nitrate run-off should be undertaken (Addiscott *et al.* 1991).

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