Symbiosis, 17 (1994) 75–86
Balaban, Philadelphia/Rehovot

The Influence of Bird Droppings on the Growth of Lichen Fragments Transplanted to Slate and Cement Substrates

R.A. ARMSTRONG
Vision Sciences, Aston University, Birmingham B4 7ET, UK
Tel. 44 021 359 3611, Fax 0121-333 4220

Received June 5, 1994; Accepted October 5, 1995

Abstract

The influence of bird droppings on the growth and fragmentation of five lichen species transplanted to slate and cement substrates was studied over a period of 15 months in South Gwynedd, Wales. The results suggested that at 15 months (1) thallus areas of *Parmelia conspersa* (Ehrh. ex Ach.)Ach were greater on both substrates with the addition of bird droppings with a greater increase on cement; (2) In *Parmelia saxatilis* (L.)Ach. and *Parmelia glabratula* ssp. *fuliginosa* (Fr. ex Duby)Laund., thallus areas were greatest on slate alone and least on cement with bird droppings, (3) in *Physcia orbicularis* (Neck.)Poetsch, thallus area was significantly reduced on cement alone compared with slate and cement treated with bird droppings, and (4) in *Xanthoria parietina* (L.)Th.Fr, thallus area was significantly greater on cement with bird droppings compared with slate and cement alone. These responses were attributable to the effect of the substrate and bird droppings on radial growth and the degree of fragmentation of the thalli. The results suggested that nutrient enrichment was more important than the substrate in determining the distribution of *P. conspersa* and *Ph. orbicularis*. However, the substrate and bird droppings were important in the remaining species, the data suggesting that *P. saxatilis* and *P. glabratula* ssp. *fuliginosa* would prefer nutrient-poor, siliceous rocks and *X. parietina* calcareous, nutrient-enriched rocks in South Gwynedd.

Keywords: lichen, transplants, growth, substrate, bird droppings

0334-5114/94 /$05.50

1. Introduction

Aspects of the substrate may influence the composition of lichen communities (Brodo, 1973; Garty et al., 1974; James et al., 1977). These include variations in aspect and slope (Wirth, 1972; Armstrong, 1974a, 1975, 1977; Pentecost, 1979), rock texture, albedo and rate of weathering (Wirth, 1972; Armstrong, 1974a; James et al., 1977), availability of moisture (Brodo, 1973) and rock chemistry (Rune, 1953; Werner, 1965; Dormaar, 1968). In a previous paper, Armstrong (1993) transplanted fragments of foliose lichen species from one substrate to another to study the effect of physico-chemical properties of the substrate on growth. Six lichen species, with contrasting distributions on different substrates in South Gwynedd, Wales were glued to pieces of slate, granite, asbestos and cement. It was concluded that lichen fragments could be transplanted successfully from one substrate to another, that growth appeared to respond to the substrate and that the results could help to explain lichen distributions. However, the distribution of some species could not be explained by the substrate alone. A factor which could significantly modify the influence of the substrate is the degree of nutrient enrichment especially by bird droppings (Barkman, 1958; Jaggard et al., 1974; Armstrong, 1984). The influence of nutrient enrichment may be so marked as to result in the establishment of a lichen community on siliceous rock which would normally be encountered on calcareous substrates (James et al., 1977). Hence, the objective of this study was to investigate the influence of nutrient enrichment by bird droppings on the growth of fragments of five species of saxicolous lichens transplanted to slate and cement substrates at a site in South Gwynedd, Wales, U.K.

2. Materials and Methods

Substrates

The experiments were carried out at the site in South Gwynedd, Wales (Nat. Grid Ref. SN 6196) described previously (Armstrong, 1974a; 1933). Outcrops of Ordovician slate are the main substrate for saxicolous lichens in this region (Armstrong, 1974a). In addition, man-made calcareous substrate e.g. asbestos roofs and cement-capped walls occur at the site and support species-poor variants of the communities developed on hard limestones in the U.K. (James et al., 1977). Two contrasting substrates, slate and cement, which vary considerably in the ratio of calcium to silica, were chosen for study. Portions of these substrates with approximately 144 mm^2 of flat surface were collected from upland rock surfaces and wall tops. All original lichen thalli present on the surface of the substrates at the time of collection were scraped off with a scalpel.

Lichen species

Five foliose lichen species, with contrasting distributions on slate and cement (Armstrong, 1993), were chosen for study: (1) *Parmelia conspersa* (Ehrh. ex Ach.)Ach. is a species of well-lit, slightly to markedly nutrient-enriched siliceous rocks (James et al., 1977; Armstrong, 1974a); (2) *Parmelia saxatilis* (L.)Ach. is frequent at two contrasting sites: (a) vertical hard rock surfaces at shaded humid sites which are not subject to direct rain, and (b) exposed, well-lit rock outcrops or boulders which are not nutrient-enriched (James et al., 1977); (3) *Parmelia glabratula* ssp. *fuliginosa* (Fr. ex Duby) Laund. is frequent on nutrient-poor siliceous rock outcrops and also occurs at shaded and maritime sites (James et al., 1977; (4) *Physcia orbicularis* (Neck.) Poetsch appears to be characteristic of nutrient-enriched sites and to be less specific to rock type (James et al., 1977); and (5) *Xanthoria parietina* (L.) Th. Fr. is a widespread species throughout the U.K. occurring on nutrient-rich, enriched or hypertrophicated bark and rock and also on calcareous rocks and walls (Hill and Woolhouse, 1966; James et al. 1977). The frequency of the five species on a sample of slate and cement substrates in south Gwynedd was reported in Armstrong (1993). *Parmelia conspersa*, *P. saxatilis* and *P. glabratula* ssp. *fuliginosa* were frequent on slate but absent on cement. *Physcia orbicularis* was present at low frequency on both substrates and *X. parietina* was frequent on cement but absent on slate. Large healthy thalli of the five species were collected on portions of the substrate and placed on horizontal boards in a private garden to equilibrate with the environment for a year before the start of the experiment. A comparison of the radial growth rates exhibited by thalli *in situ* with those equilibrating on the boards is shown in Table 1. No significant differences in growth were apparent.

Table 1. A comparison of the radial growth of five species of saxicolous lichens *in situ* with intact thalli removed on portions of the original substrate transplanted to horizontal boards (ns=no significant difference in radial growth).

Species	*in situ*	Transplanted	Students 't'
Parmelia conspersa	2.56	2.76	0.86 ns
P. saxatilis	1.5	2.06	1.84 ns
P. glabratula ssp. *fuliginosa*	1.42	1.94	2.01 ns
Physcia orbicularis	2.46	2.12	0.51 ns
Xanthoria parietina	2.35	1.99	1.53 ns

Experimental design

The transplant method has been described in detail previously (Armstrong, 1993). Essentially, thallus fragments about 50–80 mm^2 in area, with at least two healthy growing lobes, were cut from the peripheral portions of the large thalli transplanted to the boards. On 1 Aug 1992, a thallus fragment of each species was glued to each of 10 pieces of slate and 10 of cement, the fragments being allocated to portions of substrate at random. The glue (Bostik adhesive) covered the entire lower surface of the lichen fragments except for a 2 mm portion at the lobe tips. Half of the thallus fragments on both substrates, selected at random, were treated with bird droppings. Accumulations of fresh bird droppings originating from a variety of common birds (Armstrong, 1984) were collected from boards placed on a flat roof. No attempt was made to distinguish between droppings from different birds in this study. The bird droppings were homogenised with a few drops of deionised water to give a thick paste. The mean pH, determined with a pH meter, on five samples of bird droppings paste was 7.6 (Standard error=0.15). The paste was stored in a refrigerator at 5°C and used only during the week of collection. The thallus fragments received a thin smear of the paste at the beginning and end of one week at the beginning of each three-month interval for 15 months until 1 Nov 1993 (a total of 10 applications) (Armstrong, 1984). After treatment, the thalli were wetted with distilled water and remained in the laboratory at the site for 24 hr to protect them from rain. The thallus fragments were then placed on flat boards in the field away from bird perching sites. No bird droppings were observed on untreated thallus fragments during the experiment.

Data collection and analysis

The area of each thallus fragment was measured at 3 monthly intervals for 15 months by tracing the outlines of the thalli on thin plastic "clingfilm". Tracings were made on air dry thalli to avoid the problems of thallus swelling. Thallus area reflects the radial growth of the marginal lobes and the degree of fragmentation of the centre of the thallus (Armstrong, 1993). In many foliose lichens, some lobes may continue to grow radially when a considerable portion of the thallus has fragmented and disappeared (Armstrong, 1974b, 1979; Benedict and Nash, 1990). Hence, an attempt was made to determine whether the experimental treatments influenced radial growth or thallus fragmentation. The radial growth of a sample of lobes from each thallus fragment was measured at three-month intervals over 15 months using the methods described in Armstrong (1993). Initially, measurements were made on two lobes, but as the thallus enlarged, new growing points developed and later measurements were averages of between five and six lobes. The degree of thallus fragmentation in each three-month period was estimated by superimposing the outlines of the thalli on two successive occasions. These estimates were totalled over the 15-month period. Thallus area at 15 months, total radial growth and thallus fragmentation over 15 months were analysed by a three-factor (species x substrates x nutrient enrichment) analysis of variance. Comparisons between individual means were made using standard errors derived from the error mean square (Snedecor and Cochran, 1980).

3. Results

The mean areas of the transplanted thallus fragments measured at three-month intervals are shown in Fig. 1. Various responses are apparent with thallus areas increasing, decreasing, remaining relatively constant or showing a more complex response over 15 months. Analysis of variance of thallus areas at 15 months suggested: (1) no significant mean effect of substrate; (2) significant main effects of bird droppings ($P < 0.05$), and species ($P < 0.001$); and (3) significant bird droppings x substrate ($P < 0.05$), species x substrate ($P < 0.001$) and species x bird droppings interactions ($P < 0.05$). These results suggested first, that the five species responded differently to the substrates and to the addition of bird droppings, and second, that the effect of adding bird droppings varied with substrate, resulting in a greater increase in thallus areas on cement than slate. Comparisons between means of the various treatment combinations suggested first, that at 15 months, thallus areas of *P. conspersa* were greater on both substrates with the addition of bird droppings with the greatest effect on cement. Second, in *P. saxatilis* and *P. glabratula* ssp. *fuliginosa*, thallus areas were greatest on slate alone and least on cement with bird droppings. Survival of the transplants was also greater on slate alone in *P. saxatilis* (Table 2). Third, in *Ph. orbicularis*, thallus area was significantly reduced on cement alone compared with cement treated with bird droppings and on slate and fourth, in *X. parietina*, thallus area was significantly greater on cement treated with bird droppings compared with cement alone. Thallus areas of *X. parietina* declined on slate with or without bird droppings and no fragments survived on slate alone.

The analysis of variance of the total radial growth data (Table 2) suggested that the main effects of substrate and bird droppings and their interaction on radial growth were not significant. However, significant interactions were observed between species and both the substrate ($P < 0.05$) and bird droppings ($P < 0.05$) suggesting that radial growth of the five species responded differently to the treatments. The analysis of the thallus fragmentation data

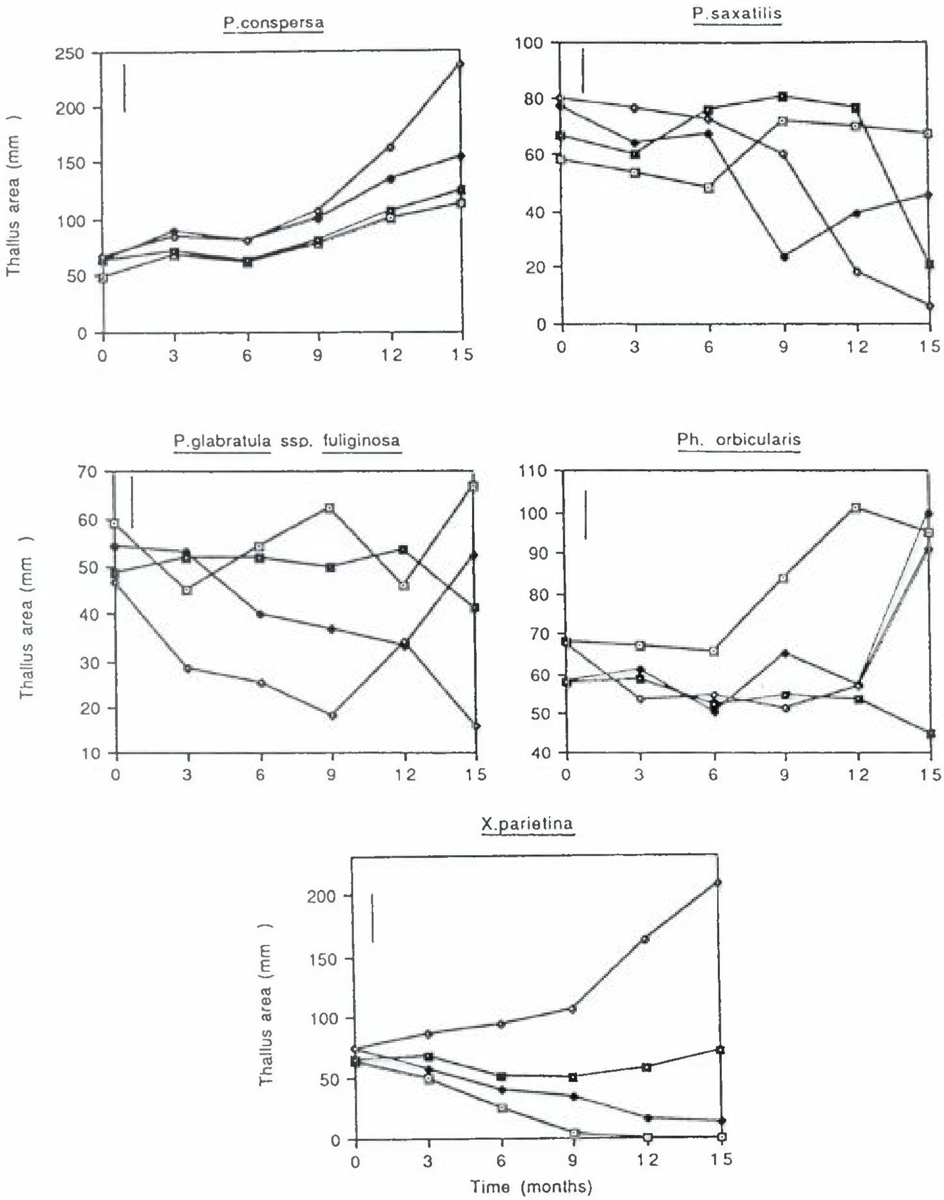

Figure 1. The influence of the substrate and the addition of bird droppings (BD) on the growth in area over 15 months of thallus fragments of five species of saxicolous lichens, (♦) slate, +BD; (□) slate, −BD; (◊) cement, +BD; (▣) cement, −BD. Analysis of variance (three-factor) on thallus areas at 15 months: Species Variance ratio (F ratio)=15.01 ($P< 0.01$), Substrate F=1.80 ($P> 0.05$), Bird droppings F=6.02 ($P< 0.05$), Substrate x Bird droppings F=4.08 ($P< 0.05$), Substrate x species F=8.91 ($P< 0.001$), Bird droppings x species F=3.52 ($P< 0.05$); Bars indicate LSD for comparison between means at 15 months.

Table 2. The mean radial growth (mm in 15 months) and number of surviving thalli (out of 5) in parentheses on 1 Nov 1993 of five saxicolous lichens transplanted to slate and cement with (+BD) and without (−BD) bird droppings

	Slate		Cement	
Species	+BD	−BD	+BD	−BD
Parmelia conspersa	2.88 (5)	2.67 (5)	4.12 (5)	2.64 (5)
P. saxatilis	1.66 (2)	2.04 (5)	1.47 (2)	0.28 (2)
P. glabratula ssp. *fuliginosa*	0.93 (4)	1.34 (5)	0.27 (4)	0.99 (5)
Physcia orbicularis	1.67 (5)	1.31 (5)	1.44 (5)	0.88 (5)
Xanthoria parietina	0.18 (3)	0.50 (0)	3.38 (5)	1.16 (5)

Analysis of variance of growth data (three-factor): Species Variance ratio (F ratio) = 10.14 (P< 0.01), Substrate F=0.36 (P> 0.05), Bird droppings F=0.57 (P> 0.05), Species x Substrate F=4.60 (P< 0.01), Species x Bird droppings F=2.27 (P< 0.05), Substrate x Bird droppings F=1.44 (P> 0.05). Least significant difference (LSD) for comparing radial growth rate means = 1.18 mm i.e. all differences between means greater than 1.18 are significantly different at the 5% level of probability.

(Table 3) was similar except that the species x bird droppings interaction was not significant. The results imply that radial growth was influenced by the substrate and bird droppings while thallus fragmentation was influenced more by the substrate. The results for the individual species suggest: (1)

Table 3. Thallus fragmentation (mm^2 in 15 months) of five saxicolous lichens transplanted to slate and cement with (+BD) and without (−BD) additions of bird droppings

	Slate		Cement	
	+BD	−BD	+BD	−BD
Parmelia conspersa	25	43	12	50
P. saxatilis	73	46	95	83
P. glabratula ssp. *fuliginosa*	36	20	34	40
Physcia orbicularis	20	16	19	41
Xanthoria parietina	63	73	30	11

Analysis of variance (three-factor): Species Variance ratio (F ratio)=9.81 (P< 0.001), Substrate F=0.33 (P> 0.05); Bird droppings F=1.43 (P> 0.05); Species x Substrate F=5.35 (P< 0.01); Species x Bird droppings F=1.63 (P> 0.05); Substrate x Bird droppings F=3.28 (P> 0.05). Least significant difference = 28 mm^2.

in *P. conspersa* and *X. parietina* an increase in radial growth and a reduction in fragmentation were responsible for increased thallus areas on cement with bird droppings; (2) significantly less fragmentation appeared to be important in determining the thallus area of *P. saxatilis* on slate alone; (3) effects on radial growth were important in determining thallus area in *P. glabratula* ssp. *fuliginosa*; and (4) in *Ph. orbicularis* thallus area on cement alone may be attributable to a combination of low radial growth and increased thallus fragmentation although neither individual effect reached statistical significance.

4. Discussion

All transplanted fragments appeared healthy and exhibited radial growth over the first few months of the experiment. However, radial growth of the transplanted thallus fragments was generally less than the corresponding intact thalli *in situ* and on the boards. This was anticipated since thallus fragments have lower growth rates than whole thalli (Armstrong, 1984). In addition, the thallus fragments appeared to respond consistently to the experimental treatments suggesting successful transplantation. However, some species e.g., *P. saxatilis* and *P. glabratula* ssp. *fuliginosa* did not show a gain in thallus areas over 15 months in any treatment combination and these species may have responded detrimentally to the transplant. The data suggested that the species responded to the substrate and the addition of bird droppings. At first, the transplants were separated from the substrate by a layer of glue. Hence, it was likely that the presence or absence of ions leached from the substrate was an important factor influencing growth. The addition of bird droppings had a marked effect on growth on all species. This supports previous studies which have emphasised the influence of nutrient enrichment of the substrate in determining lichen distributions (Barkman, 1958; James et al., 1977; Armstrong, 1984). Hence in *P. conspersa*, the addition of bird droppings increased thallus areas on both substrates and especially on cement, suggesting that the presence of bird droppings was the more important factor in this species. The importance of nutrient enrichment was also suggested by the data of Jones and Platt (1969) who found that additions of a nutrient solution enhanced growth of *P. conspersa*. In *P. saxatilis* and *P. glabratula* ssp. *fuliginosa*, best growth was achieved on slate alone and least on cement in the presence of bird droppings, suggesting a nutrient-poor siliceous substrate was important for these two species. These results are consistent with previous data (Armstrong, 1984) which showed that radial growth was increased in *P. conspersa* and decreased in *P. saxatilis* and *P. glabratula* ssp. *fuliginosa* in the presence of bird droppings. In *X. parietina*, the greatest thallus area occurred on cement with the addition of bird droppings, suggesting that both a calcareous substrate and nutrient enrichment were necessary for growth and survival. In *Ph. orbicularis*, bird droppings appeared to be necessary for the transplants to grow successfully on cement but not on slate. A chemical interaction involving a constituent of bird droppings that may neutralise an inhibitory influence of cement could be one factor which could explain this effect.

Radial growth is dependent on processes that occur largely at the lobe tips (Armstrong, 1979). Many factors of the substrate could influence these processes including roughness and fine texture of the rock, rock hardness and friability and ion concentrations. Substrate chemistry may be of particular importance and, by influencing thallus pH, could affect algal photosynthesis (Hill, 1971), respiration (Braddeley et al., 1971) and the leakage of carbon compounds (Hill and Smith, 1972). In addition, minerals and organic substances are in different chemical states under different pH regimes, and pH may influence: (1) the availability of different ions; (2) their diffusion rates; and (3) the presence and activity of toxic elements (Brodo, 1973). By contrast, thallus fragmentation may be a degenerative process which occurs with increasing frequency and involves greater thallus areas in larger thalli (Armstrong, 1974c). In large thalli, a decrease in algal cell density at the thallus centre may lead to a reduction in photosynthesis of central tissue. In addition, there could be a reduction in the translocation of nutrients from the thallus margin to the centre. The substrate, in particular, appears to increase the degree of fragmentation in some species, e.g., in *Ph. orbicularis* on cement alone. It is possible that changes in the pH of the thallus resulting in the leaching of ions could explain this effect. In *X. parietina*, the absence of calcium may lead to leaching of large quantities of potassium while the same phenomenon occurs in *P. saxatilis* in the presence of calcium (Fletcher, 1976). Hence, leaching of potassium could impair the integrity of cell membranes and enhance the fragmentation of ageing thallus tissue. Consistent with this suggestion, Armstrong (1990) found that the addition of calcium salts increased the degree of thallus fragmentation in *P. saxatilis.*

The experiment has several limitations. First, some species, e.g., *P. saxatilis* and *P. glabratula* ssp. *fuliginosa* may have been influenced by the transplant procedure. Second, 15 months may be too short a period for all treatments to reveal their effects. Third, bird droppings were added to thalli intermittently, whereas a more continuous regime may have been necessary to test whether some species characteristic of calcareous environments, e.g., *X. parietina* could survive on slate. Despite these limitations the data do appear to help explain the distributions of the five species in south Gwynedd. The data suggest the following predictions: (1) nutrient enrichment would be more important than the substrate in determining the distribution of *P. conspersa*; (2) *P. saxatilis* and *P. glabratula* ssp. *fuliginosa* would prefer nutrient-poor, siliceous rocks; (3) *X. parietina* which would be more abundant on nutrient-enriched cement, would be present at low frequency on cement alone and absent on slate; and (4) *Ph. orbicularis* would be frequent on slate, whether nutrient-enriched or not, and on nutrient-enriched cement, but would be infrequent on cement alone. First, *P. conspersa* is a species of nutrient-enriched siliceous rocks in the U.K. (James et al., 1977). However, the data would not explain the absence of *P. conspersa* from nutrient-enriched calcareous substrates like asbestos roofs and cement walls in south Gwynedd (Armstrong, 1993). It is possible that propagules of *P. conspersa* cannot establish on cement since siliceous rock lichens require an extremely stable, hard surface for colonization (Brodo, 1973). Alternatively, established thalli may not be able to compete on calcareous substrates. Second, both *P. saxatilis* and *P. glabratula* ssp. *fuliginosa* occur on nutrient-poor siliceous rocks in the U.K. (James et al., 1977). Bird droppings may inhibit these species by smothering of thalli, increasing the pH or adding inhibitory chemicals (Armstrong, 1984). There is little evidence that uric acid, the most important nitrogenous constituent of bird droppings, is a significant factor in this inhibition (Armstrong, 1984). The addition of calcium and magnesium salts inhibited radial growth of *P. saxatilis* (Armstrong, 1990), suggesting that an increase in pH could be the critical factor in this species. Third, *X. parietina* occurs in nutrient-rich or enriched communities of relatively high pH on bark or rock (James et al., 1977). The experiment suggested that both a calcareous substrate and nutrient enrichment were necessary for growth of this species. However, in the field, *X. parietina* occurs on non-calcareous, nutrient-enriched substrates, e.g., in the supralittoral zone on maritime slate (Arstrong, 1974a). This may be dependent on the type of or exposure to nutrient enrichment encountered by the thalli in this zone. In south Gwynedd, *X. parietina* was absent from a large sample of inland slate rocks (Armstrong, 1974a), many of which showed some evidence of bird droppings which would be consistent with the experimental data. Fourth, *Ph. orbicularis* occurs on both slate and cement substrates in south Gwynedd as predicted by the data (Armstrong, 1993). However, further observations would be required to demonstrate that this species was distributed differently on nutrient-rich compared with nutrient-poor cement.

REFERENCES

Armstrong, R.A. 1974a. The descriptive ecology of saxicolous lichens in an area of South Merionethshire, Wales. *J. Ecol.* **62:** 33–45.

Armstrong, R.A. 1974b. Growth phases in the life of a lichen thallus. *New Phytol.* **73:** 913–918.

Armstrong, R.A. 1974c. The structure and dynamics of saxicolous lichen communities. D. Phil. Thesis, University of Oxford.

Armstrong, R.A. 1975. The influence of aspect on the pattern of seasonal growth in the lichen *Parmelia glabratula* ssp. *fuliginosa*. *New Phytol.* **75:** 245–251.

Armstrong, R.A. 1977. The response of lichen growth to transplantation to rock surfaces of different aspect. *New Phytol.* **78:** 473–478.

Armstrong, R.A. 1979. Growth and regeneration of lichen thalli with the central portions artificially removed. *Env. Exp. Bot.* **21:** 116–120.

Armstrong, R.A. 1984. The influence of bird droppings and uric acid on the growth of five species of saxicolous lichens. *Env. Exp. Bot.* **24:** 95–99.

Armstrong, R.A. 1990. The influence of calcium and magnesium on the growth of the lichens *Xanthoria parietina* and *Parmelia saxatilis*. *Env. Exp. Bot.* **30:** 51–57.

Armstrong, R.A. 1993. The growth of six saxicolous lichens transplanted to lime-rich and lime-poor substrates in South Gwynedd, Wales. *Symbiosis* **15:** 257–267.

Baddeley, M.S., Ferry, B.W., and Finegan, E.J. 1971. A new method of measuring lichen respiration: response of selected species to temperature, pH and sulphur dioxide. *Lichenologist* **5:** 18–25.

Barkman, J.J. 1958. *Phytosociology and Ecology of Cryptogamic Epiphytes.* Assen, The Netherlands.

Benedict, J.D. and Nash, T.H. 1990. Radial growth and habitat selection by morphologically similar chemotypes of *Xanthoparmelia*. *Bryologist* **93:** 319–327.

Brodo, I.M. 1973. Substrate ecology. In: *The Lichens.* V. Ahmadjian and M.E. Hale, eds. Academic Press, New York, pp. 401–441.

Dormaar, J.F. 1968. Infrared absorption spectra of mineral matter in saxicolous lichens and associated mosses. *Can. J. Earth Sci.* **5:** 223–230.

Fletcher, A. 1976. Nutritional aspects of marine and maritime lichen ecology. In: *Lichenology: Progress and Problems.* D.H. Brown, D.L. Hawksworth and R.H. Bailey, eds. Academic Press, New York.

Garty, J., Gal, M., and Galun, M. 1974. The relationship between physicochemical soil properties and substrate choice of "multisubstrate" lichen species. *Lichenologist* **6:** 146–150.

Hill, D.J. 1971. Experimental study of the effect of sulphite on lichens with reference to atmospheric pollution. *New Phytol.* **70:** 831–836.

Hill, D.J. and Woolhouse, H.W. 1966. Aspects of the autecology of *Xanthoria parietina* agg. *Lichenologist* **3:** 207–214.

Hill, D.J. and Smith, D.C. 1972. Lichen physiology XII. The 'inhibition technique'. *New Phytol.* **71:** 15–30.

Jaggard, S.J., Seviour, J.A., and Hill, D.J. 1974. The distribution of some ornithocoprophilous lichen species on carboniferous limestone in the Malham area. *Trans. Nat. Hist. Soc. Northumb.* **41:** 194–203.

James, P.W., Hawksworth, D.L., and Rose, F. 1977. Lichen communities in the British Isles: a preliminary conspectus. In: *Lichen Ecology.* M.R.D. Seaward, ed. Academic Press, New York, pp. 295–419.

Jones, J.M. and Platt, R.B. 1969. Effects of ionizing radiation, climate and nutrition on growth and structure of a lichen *Parmelia conspersa* (Ach.). *Ach. Radioecol.* **2:** 111–119.

Pentecost, A. 1979. Aspect and slope preferences in a saxicolous lichen community. *Lichenol.* **11:** 81–83.

Rune, O. 1953. Plant life on serpentines and related rocks in the north of Sweden. *Acta Phytogeog. Suecia* **31:** 1–139.

Snedecor, G.W. and Cochran, W.G. 1980. *Statistical Methods.* 7th ed. Iowa State Press, Ames, Iowa.

Werner, R.G. 1956. Etudes ecologiques sur les lichens des terrains schisteux maritimes. *Bull. Sci. Nancy [N.S.]* **15:** 137–152.

Wirth, V. 1972. Die Silikatflechten-Gemeinschaften im ausseralpinen Zentraleuropa. *Dissert. Bot.* **17:** 1–306.