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The Growth of Six Saxicolous Lichens Transplanted to Lime-rich and Lime-poor Substrates in South Gwynedd, Wales

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Abstract

The objectives of this study were to investigate: (1) whether foliose lichen thalli could be transplanted from one substrate to another and (2) whether such transplants could be used to study the influence of the substrate on growth. Hence, six saxicolous lichens, with contrasting distributions on lime-rich and lime-poor substrates in South Gwynedd, Wales, were transplanted onto slate, granite, asbestos and cement. Fragments of the perimeters of thalli were glued to the different substrates using Bostic adhesive. *Parmelia conspersa* (Ehrh. ex Ach.)Ach. and *Parmelia saxatilis* (L.)Ach., fragments increased in area over 15 months on slate and granite but decreased in area or did not survive on asbestos and cement. Fragments of *Xanthoria parietina* (L.)Th.Fr. and *Physcia tenella* (Scop.)DC. em Bitt. did not survive on slate and granite while some fragments survived but grew poorly on asbestos and cement. *Parmelia glabratula* ssp. *fuliginosa* (Fr. ex Duby)Laund. fragments decreased in area on all substrates and especially on cement and asbestos while *Physcia orbicularis* (Neck.)Poetsch fragments increased in area on granite and cement, decreased on asbestos and did not change significantly on slate. The results suggested that the distribution of *P. conspersa* and *P. saxatilis* was determined primarily by the physico-chemical properties of the substrate. By contrast, *P. glabratula* ssp. *fuliginosa* may have responded to the transplant procedure while *X. parietina Ph. tenella* and *Ph. orbicularis* may require nutrient enrichment to grow successfully on a substrate.

Keywords: lichen, substrate, transplantation, growth, nutrient enrichment

1. Introduction

The substrate has an important influence on the composition of lichen communities (Brodo, 1973; Garty, Gal and Galun, 1974; James,Hawksworth and Rose, 1977). However, the absence of a species on a particular substrate could be due to numerous factors including the physico-chemical properties of the substrate (Brodo, 1973), the level of nutrient enrichment (Pentecost, 1980; Armstrong, 1984) and the effects of competitive exclusion (Armstrong, 1982). Hence, the absence of a species on a substrate could be due to the influence of any of these factors on establishment (Armstrong, 1981) or growth (Armstrong, 1990). Substrate factors include 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). However, to study the influence of the substrate on growth, a method of transplanting and growing lichen thalli on different surfaces is required. In the majority of lichen transplant studies (Brodo, 1961; Leblanc and Rao, 1966; Armstrong, 1977, 1990; Benedict, 1990), foliose or crustose thalli were transplanted on a portion of the original substrate. Fewer studies have removed the thallus completely from its substrate. Armstrong (1982) cut fragments from the perimeters of large thalli and glued them to pieces of slate in order to study lichen competition. Neither cutting nor glueing appeared to influence growth of the fragments (Armstrong, 1982). Hence, the objectives of the present study were: (1) to determine whether this method could be used to transplant foliose lichens from one substrate to another, and (2) whether such transplants could be used to study the influence of the substrate on growth. Fragments of six saxicolous lichens, with contrasting distributions on lime-rich and lime-free surfaces in South Gwynedd, Wales were glued to four different substrates viz. slate, granite, asbestos and cement. The experiment would be a test of whether the physico-chemical properties of the substrate were important in determining the distribution of the lichens.

2. Materials and Methods

Substrata

The experiment was carried out at a site in south Gwynedd, Wales (Nat. Grid Ref. SN 6196) described previously (Armstrong, 1974a). The geology of the region is primarily Ordovician slate but outcrops of granite also occur at some inland sites (Armstrong, 1974a). In addition, asbestos-cement (subsequently called asbestos) is used as a roofing material while parian-cement (cement) is used to cap old walls in South Gwynedd. By contrast with slate and granite, asbestos and cement are high in calcium and magnesium and low in silica. Portions of slate, granite, asbestos and cement, with approximately 144 mm^2 of flat surface, were used in the experiment. Pieces of slate and granite were removed from several upland rock surfaces while portions of asbestos and cement were collected from garage roofs and wall tops. All lichen thalli present on the surface of the substrates were removed.

Lichen species

Six foliose lichens, common on saxicolous substrata at the site were chosen for study. Large, healthy thalli of *Parmelia conspersa* (Ehrh. ex. Ach.), *Parmelia glabratula* ssp. *fuliginosa* (Fr. ex Duby)Laund, *Parmelia saxatilis* (L.)Ach. and *Physcia orbicularis* (Neck.)Poetsch were collected on pieces of slate or granite from several rock surfaces as close as possible to the transplant site. *Xanthoria parietina* (L.)Th.Fr. and *Physcia tenella* (Scop.)DC.em.Bitt. were collected on small, flat portions of asbestos or cement adjacent to the transplant site. All thalli were placed on horizontal boards in a private garden for a year before transplantation to the various substrates. To investigate the frequency of the six species on the four substrates at the site, 23 slate rock surfaces, 10 granite and 15 each of asbestos roofs and cement capped walls were studied. On each surface, 10 to 20, 10×10 cm quadrats were randomly located, the number depending on the surface area of the substrate. The presence/absence of each of the six species was recorded for each quadrat and the data expressed as a percentage frequency of each species on each surface.

Climatic data

The climate during the experiment could influence the growth of the transplants. Hence, data on total rainfall and the number of sunshine hours per month, two factors which are important in determining monthly growth (Armstrong, 1993; in press), were obtained for the period of the experiment from the Welsh Plant Breeding Station, Plas Gogerddan near Aberystwyth, 8 miles to the south and at the same altitude as the sample site. The data (Fig. 1) show that rainfall was low in four out of the first six months of the experiment. In addition, low rainfall occurred in combination with a high frequency of sunshine hours from April to June 1988.

Experimental design

Fragments of each of the six species were transplanted to five replicate pieces of the four substrates. Thallus fragments, approximately 70–150 mm^2 in area,

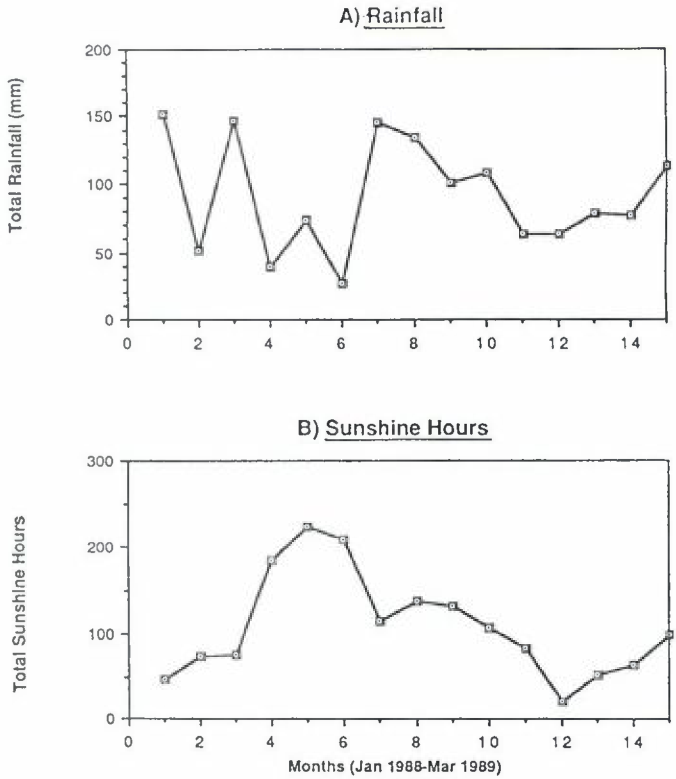

Figure 1. Distribution of (A) total rainfall (mm), and (B) frequency of sunshine hours during the 15 months of the experiment.

with at least two healthy growing lobes, were cut from thalli at similar stages of development. The size of the fragment varied between species depending on lobe morphology. However, there were no significant differences in mean area of the fragments of an individual species on the four substrates at the start of the experiment. Fragments of each species were allocated at random to the substrates. The glue (Bostic adhesive) covered the entire lower surface of the lichen fragment except for a 2 mm portion at the lobe tips. Unsuccessful transplants, due to a failure of glueing, were replaced after three months growth. No further fragments were replaced during the experiment. The pieces of substrate with the transplanted fragments were placed on flat boards away from bird perching sites. No bird droppings were observed on the thallus fragments during the experiment.

Data collection and analysis

The area of each thallus was measured at three monthly intervals for 15 months using the method of Armstrong (1992). Lichen thalli may continue to grow radially even though the centre has fragmented (Armstrong, 1974b; Benedict and Nash, 1990). Hence, the radial growth of a sample of lobes was measured. Small spots of red acrylic paint were placed at 1 mm intervals along guidelines oriented along the direction of growth of a lobe. Radial growth was then measured using the method of Armstrong (1975). Lobes of *Ph. tenella* which have an ascending pattern of lobe growth, could not be measured successfully by this method. The thallus area data were analysed as follows: (1) the area of the thallus at the end of the experiment was analysed by a two-factor split-plot analysis of variance with substrate type as the major factor and lichen species as the subplot factor, (2) for each species, a two factor split-plot analysis of variance was carried out with substrate type as the major factor and sampling time as the subplot factor, and (3) the change in thallus area over 15 months was analysed by a two factor split-plot analysis of variance with substrate type as the major factor and species as the subplot factor.

3. Results

The percent frequency of the six species on the four substrates at the site is shown in Table 1. *Parmelia conspersa*, *P. glabratula* ssp. *fuliginosa* and *P. saxatilis* were present on slate and granite but were not recorded on asbestos or cement. *Parmelia saxatilis* and *P. glabratula* ssp. *fuliginosa* appeared to be

Table 1. Mean percent frequency (with standard deviation in parentheses) of six species of saxicolous lichens on four substrates in South Gwynedd, Wales

	Substrate			
	Slate	Granite	Cement	Asbestos
Number of surfaces sampled	23	10	15	15
Parmelia conspersa	22 (7.3)	12.5 (7.3)	0	0
Parmelia glabratula ssp. *fuliginosa*	42 (6.2)	75 (9.0)	0	0
Parmelia saxatilis	31 (4.9)	72 (10.4)	0	0
Physcia orbicularis	12 (4.2)	0	12 (6.8)	9 (3.7)
Xanthoria parietina	0	0	38 (4.4)	56 (5.5)
Physcia tenella	0	0	8 (2.4)	38 (5.7)

Table 2. The mean radial growth (mm in 15 months) and number of surviving thalli (out of 5) in parentheses on 1, April 1989) of six saxicolous lichens transplanted to four different substrates

	Substrate			
	Slate	Granite	Cement	Asbestos
Parmelia conspersa	2.47 (5)	3.32 (5)	1.50 (3)	0.68 (2)
Parmelia glabratula ssp. *fuliginosa*	1.15 (5)	1.10 (5)	1.02 (2)	0 (0)
Parmelia saxatilis	2.36 (5)	2.42 (5)	1.02 (3)	0.32 (0)
Physcia orbicularis	0.87 (4)	1.56 (5)	1.84 (5)	0 (0)
Xanthoria parietina	0 (0)	0.15 (0)	0.48 (4)	0.53 (5)
Physcia tenella	nm (0)	nm (0)	nm (5)	nm (5)

Analysis of variance of growth data (1-way). *P. conspersa*: F=4.82 (3,16 d.f., $P<0.05$, LSD=0.92); *P. glabratula* ssp. *fuliginosa* (excluding asbestos data): F=2.53 (2,14 d.f., $P>0.05$); *P. saxatilis*: F=6.6 (3,16 d.f., $P<0.01$, LSD=0.59); *X. parietina* (excluding slate data): F=2.4 (2,14 d.f., $P>0.05$); nm=not measured.

more frequent on granite than slate. By contrast, *X. parietina* and *Ph. tenella* were present on asbestos and cement but were not recorded on slate and granite. *Physcia orbicularis* was present in low frequency on slate, cement and asbestos and absent on granite.

The total radial growth over 15 months and the number of surviving thallus fragments are shown in Table 2. Individual lobes may grow radially despite the tendency of the thallus centre to fragment, e.g. *P. glabratula* ssp. *fuliginosa* on granite and *P. saxatilis* on cement. No fragments of *X. parietina* and *Ph. tenella* survived on slate and granite or of *P. glabratula* ssp. *fuliginosa*, *P. saxatilis* and *Ph. orbicularis* on asbestos. Some fragments of *P. conspersa*, *P. glabratula* ssp. *fuliginosa*, *P. saxatilis* and *Ph. orbicularis* survived on cement.

The mean area of the transplanted fragments of each species on each substrate measured at three month intervals is shown in Fig. 2. Significant species x substrate interaction terms for thallus area at the end of the experiment (F=13.87, 15,60d.f., $P<0.001$) indicated that the six species responded differently to transplantation to the four substrates. Various responses were observed over the period of the experiment: (1) thallus are increased with or without an initial decline in area, e.g. *P. conspersa* on granite and *P. saxatilis* on slate and granite; (2) thallus area decreased with few or no fragments surviving after 15 months, e.g. *P. conspersa* and *P. glabratula* ssp. *fuliginosa* on asbestos, and *X. parietina* and *Ph. tenella* on slate and granite; (3) little change in thallus area occurred over 15 months, e.g. *Ph. orbicularis* on slate

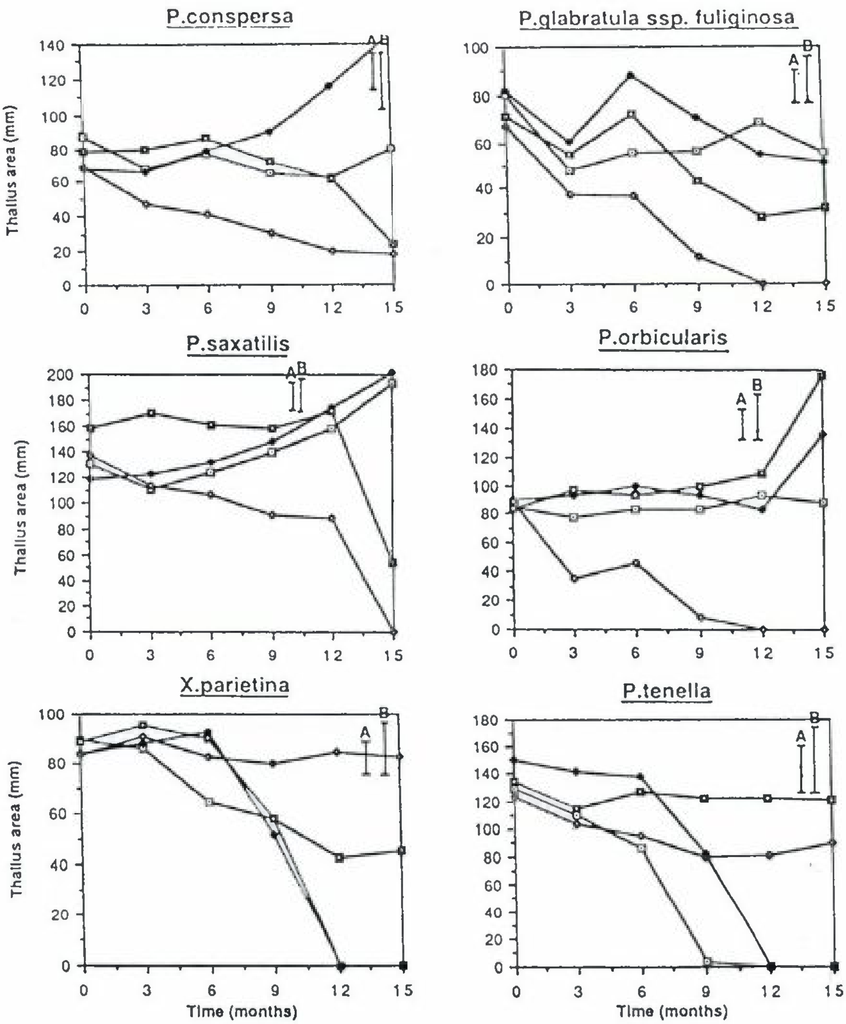

Figure 2. Mean thallus area (mm^2) of fragments of six saxicolous lichens glued to (⊡) slate; (♦) granite; (□) parian-cement; (◇) asbestos-cement. Analysis of variance: (a) *Parmelia conspersa* Substrate F=6.82 (4,12 d.f.; P<0.01), interaction with growth period F=4.66 (20,75 d.f.; P<0.01; *Parmelia glabratula* ssp. *fuliginosa* Substrate F=4.84 (4,12 d.f.; P<0.05); growth period F=11.16 (5,75 d.f.; P<0.001); (c) *Parmelia saxatilis* Substrate F=16.46 (4,12 d.f.; P<0.001); interaction with growth period F=8.09 (20,75 d.f.; P<0.001) and (d) *Physcia orbicularis* Substrate F=8.36 (4,12 d.f.; P<0.01); interaction with growth period F=6.87 (20,75 d.f.; P<0.001); (e) *Xanthoria parietina* Substrate F=22.58 (4,12 d.f.; P<0.001); growth period F=169.16 (5,75 d.f.; P<0.001); interaction F=23.37 (20,75 d.f.; P<0.001); (f) *Physcia tenella* Substrate F=9.94 (4,12 d.f.; P<0.01); growth period F=42.35 (5,75 d.f.; P<0.001); interaction F=9.69 (20,75 d.f.; P<0.001). Bars indicate Least Significant Difference for comparing (A) treatment means within a substrate; (B) treatment means between substrates.

and *X. parietina* on asbestos, or (4) a more complex response with periods of growth followed by thallus fragmentation, e.g. *P. glabratula* ssp. *fuliginosa* on granite and cement.

In *P. conspersa*, thallus area increased significantly over 15 months on granite but declined on the lime-rich substrates. Thallus fragmentation began earlier on asbestos compared with cement. Radial growth was observed on cement in the early months of the experiment. In *P. glabratula* ssp. *fuliginosa*, no significant increase in thallus area was recorded on any substrate over 15 months. However, the decrease in area was greater on the lime-rich surfaces. Radial growth of some perimeter lobes was observed on slate, granite and cement. In *P. saxatilis*, thallus area increased significantly on slate and granite but declined after about 12 months on asbestos and cement. In *Ph. orbicularis*, significant increases in area were observed on granite and cement, little change occurred on slate and the thalli did not survive on asbestos. In *X. parietina* and *Ph. tenella*, the thalli fragmented completely on slate and granite but survived on the lime-rich surfaces. On the lime-poor substrates, lobes of *X. parietina* were observed to shrink and lose colour. In addition, on the lime-rich surfaces, a greater reduction in area was observed in *X. parietina* on cement.

4. Discussion

The discussion will consider (1) whether lichen fragments can be transplanted successfully from one substrate to another, (2) whether the transplants responded to the different substrates, and (3) whether the method may help to explain the distribution of the lichens studied in South Gwynedd.

The transplant procedure was carried out in two stages. First lichen thalli were removed from a site in the field on pieces of the original substrate and grown at the transplant site for a year. Second, fragments were cut from the lichen thalli which were then glued onto various substrates. There are several limitations to this procedure. First, many of the lichen thalli originated from steep rock surfaces while the experiment was conducted on horizontal boards. Hence, the environment of the transplant site will differ from that of the site of origin of the thalli. This problem should be reduced by allowing the thalli to equilibrate with the environment of the transplant site for a year. However, it is possible that the initial transplant may effect the growth of the thalli, so that the fragments perform poorly when transplanted between substrates. Second, cutting up the thalli may damage hyphae and algal cells and result in the leakage of nutrients. However, previous experiments (Armstrong, 1982, 1992) suggested that foliose lichen thalli regenerate readily from cut fragments.

Third, the glue may influence growth directly but no such effects were observed in previous experiments (Armstrong, 1982). Fourth, the transplants may be vulnerable to an unfavourable climate especially at the beginning of the experiment. Total rainfall was low in four out of the first six months of growth and from April to June 1988, occurred in combination with a high frequency of sunshine hours, factors which could have been unfavourable to growth (Armstrong, 1983, in press). Hence, the timing of a transplant experiment in the field may be critical. Despite these problems, *P. conspersa*, *P. saxatilis* and *Ph. orbicularis* fragments increased in area on some substrates, suggesting successful transplantation. However, fragments of the remaining species did not increase in area on any substrate. Hence, these species may have responded to the transplantation procedure or additional factors were necessary for successful growth, e.g. nutrient enrichment (Pentecost, 1980; Armstrong, 1984).

The extent to which the growth of the lichen fragments was influenced by the physico-chemical properties of the substrate is unclear. The glue may have prevented the rhizinae from penetrating the surface of the rock. Hence, the transplants may have been influenced by the pH and levels of soluble ions leached from the surface rather than by minerals in the substrate. By contrast, an established thallus could be influenced by both of these factors. Furthermore, a 15 month experimental period may have been inadequate to establish whether the substrate influences growth. Lichen thalli usually respond to additions of nutrients within a year (Armstrong, 1984, 1990) but a longer period may be necessary to study the chemical properties of the substrate.

Despite these limitations, the experiment does appear to help to explain the distribution of some of the species on lime-rich and lime-poor rocks in South Gwynedd. For example, *P. conspersa* and *P. saxatilis* are frequent on lime-poor substrates and absent from the lime-rich substrates studied at the site. In the experiment, thallus fragments did not survive on asbestos and cement. Hence, a direct effect of the substrate on growth could explain the distribution of the two species. The lime-rich and lime-poor substrates differ in the level of calcium, magnesium, metal ions and silica (Werner, 1965) as well as in physical properties, e.g. porosity. In previous experiments, thalli of *P. saxatilis* grew poorly on slate when calcium or magnesium carbonate was added to the thalli (Armstrong, 1990), suggesting that this species is intolerant of a high pH or to the presence of calcium and magnesium. These factors may influence the growth of individual symbionts (Hale, 1974) and influence the transfer of carbohydrate from alga to fungus (Green, 1970; Hill and Smith, 1972). Hence, further experiments should enable the chemical effects of the substrate to be explained in physiological terms.

By contrast, the results for the remaining species cannot be attributed to the substrate alone. *Xanthoria parietina* and *Ph. tenella* occur on lime-rich substrates at the site and are absent on lime-poor substrates, with the exception of slate rocks near the sea (Armstrong, 1990). Although fragments did not survive on slate and granite, a result consistent with this distribution, growth was also poor on the lime-rich substrates. This could be due to the various effects of transplanting. Alternatively, lack of nutrient enrichment could have been a factor in the experiment. *Xanthoria parietina* and *Ph. tenella* are often recorded at nutrient enriched sites (James et al., 1977) and addition of bird droppings (Armstrong, 1984) enabled *X. parietina* thalli to grow on slate at inland sites in South Gwynedd. Hence, a suitable substrate and nutrient enrichment may be necessary for the successful growth of *X. parietina.* An experiment in which *X. parietina* fragments were transplanted to lime-rich substrates with and without the addition of bird droppings would test this hypothesis. *Parmelia glabratula* ssp. *fuliginosa* fragments decreased in area on all substrates. Since growth of this species is inhibited by the addition of bird droppings (Armstrong, 1984) it is more likely that the response was due to a transplanting effect. The response of *Ph. orbicularis* is especially difficult to explain. First, transplanted fragments increased in area on granite but this species was absent from the granite rock surfaces in the field. This absence could be due to a competitive effect (Armstrong, 1982). Second, *Ph. orbicularis* occurs on asbestos in the field but thallus fragments grew poorly on asbestos in the experiment. Growth could have been affected by transplantation or the lack of nutrient enrichment, hypotheses which could be tested in further experiments.

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