

LICHENOMETRY AS A METHOD FOR HOLOCENE DATING: LIMITS IN ITS APPLICATIONS AND RELIABILITY (*)

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ABSTRACT- *Lichenometry as a method for Holocene dating: limits in its applications and reliability* - *Il Quaternario*, 6(1), 1993, 77-86 - Guidelines of the lichenometric method applied to studies of Holocene absolute age determinations are traced on a bibliographic basis. Particular care is given to the Italian slope of the Alps. The method is critically revisited and the necessity of considering various biotic and abiotic factors influencing lichens' growth and reliability of measures is pointed out. A list of such factors with bibliographic references is proposed. Limits of this method and its applications are stressed.

RIASSUNTO - *La lichenometria come metodo di datazione per l'Olocene: limiti di applicazione e affidabilità* - *Il Quaternario*, 6(1), 1993, 77-86 - Vengono tracciate su base bibliografica le linee essenziali del metodo lichenometrico applicato a studi di datazione assoluta di fenomeni olocenici, soffermandosi, in particolare, sulla situazione del versante italiano dell'arco alpino. Si procede alla revisione critica del metodo, da cui deriva la necessità di considerare numerosi fattori biotici e abiotici che in vario modo influenzano la crescita dei licheni e l'affidabilità delle misure in campo. Viene proposto un elenco dettagliato di tali fattori corredato da specifici riferimenti bibliografici. Si evidenziano infine i limiti del metodo e le sue attuali possibilità applicative.

Key-words: Lichens, lichenometry, Italian Alps

Parole chiave: Licheni, lichenometria, Alpi italiane

1. INTRODUCTION

The validity of lichens as a biological tool for qualitative and quantitative evaluations of natural and anthropic environments is widely documented. Tests have shown that it is possible to use lichens as bioindicators (Nash III & Wirth, 1990) and biodeteriogens (Seaward, 1977; Nimis *et al.*, 1992). The possibility of using these organisms as instruments for measuring time and space is also of primary importance (Lawrey, 1985). It is this latter potential that has become the focus of much research since the 1960s. Lichens, unlike other plants, are characterized by slow growth and longevity. These two important ecophysiological peculiarities, the result of the interaction of numerous environmental and physiological factors, can provide, if correlated to the time factor, precious information on the age of colonized surfaces.

The branch of lichenology that deals with the use of lichens as a dating instrument, is called lichenometry which is based on geometric-type methodologies. The interest aroused by the first application, proposed by the Austrian scholar Beschel (1950, 1957, 1958, 1961), centres on its potential as a means of obtaining absolute dating, especially when other dating techniques are not feasible, [¹⁴C assay, dendrochronology, thermoluminescence (Innes, 1988)]. This potentiality found an

immediate response from geomorphologists, who have written most of articles on lichenometry, as well as archaeologists and naturalists dealing with problems concerning late Quaternary dating.

2. THE LICHENOMETRIC TECHNIQUE

The method proposed by Beschel is essentially based on the fixed relation between the diameter of the lichen's thallus and its age. This ratio permits us, given a dated substratum, to deduce the age of the lichens present on the substratum. The ratio must be applied to the thallus of the species with the largest diameter on the surface being examined. The author in fact sustains that the larger size corresponds to the maximum growth of the species used as an indicator. Non-dated substrata can, on the other hand, be chronologically identified on the basis of extrapolated curves.

The technique proposed presents limits, already in part pointed out by Beschel. Lichens growth depends on the interaction of climatic parameters (rain, snow) in coincidence with the altitude factor ⁽¹⁾. An analogous conditioning concerns the chemico-physical characteristics of the substratum, for instance its stability and

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⁽¹⁾ Beschel (1958) indicates the ratio between precipitations and altitude as a trigonometric function of "hygrocontinentiality", a concept already expressed by Gams in 1932.

pH (Beschel, 1950). Another condition governing the choice of the thallus to be measured is its shape, which must be absolutely circular. There is therefore the need to introduce a new corrective factor, defined by the author as the "lichen factor", which considers the growth of the thallus in relation to time.

3. POST-BESCHEL LICHENOMETRIC APPLICATIONS ON THE ITALIAN ALPS

Several authors subsequently experimented the technique introduced by Beschel (Webber & Andrews, 1973). In particular his experiment conducted on the moraines of the Gran Paradiso National Park (Beschel, 1958) was taken up and extended to other sectors of the Italian Alps.

Belloni (1970; 1973), in his surveys in Valfurva and Val di Solda (province of Sondrio), went beyond Beschel's method and recognized the need to consider microclimates that are the same, and substrata that are lithologically homogeneous.

Among other things, he compares the growth of the *Rhizocarpon geographicum*, an exclusively siliceous species, in relation to the lithology considered: from 0.38 mm/per annum on dioritic gneiss to 1.00 mm/per annum on altered phyllade (Belloni, 1973).

Pelfini (1988), having conducted lichenometric surveys in the same area and with the same lichen species (*Rhizocarpon geographicum* and *Aspicilia cinerea*), believes that only for by carrying out surveys on vast surfaces and on numerous species can the effects induced by lithologic, microclimatic, microenvironmental variability and by numerous environmental factors be eliminated. Measurements were made on isolated individuals of a circular shape and of which only the minimum diameter was considered (inscribed circle).

Analogous procedures were followed by Strada (1988) in a study on the glacier of Lys (Monte Rosa, Aosta Valley), and Baroni & Carton (1991a, 1991b) who refer to the small glacier of Pispagna and to that of Lobbia in the Adamello Group.

Further applications of the Beschel method were carried out by Porter & Orombelli (1980) and Orombelli & Porter (1983) on the southern side of the Mont Blanc massif in the Aosta Valley. However, they used the minimum diameter of the largest lichen thallus (inscribed circle) present on the moraine. Only in work conducted in 1983 and in the same area, do the two authors point out the limits of traditional lichenometric techniques, and sustain that these are valid only for local areas.

Comparing the growth curves shown in Figure 1, all relative to the same lichen species (*Rhizocarpon geographicum*) it becomes difficult to define univocal quantifiable parameters. These difficulties were already pointed out by Porter (1981) in a study carried out on the *Rhizo-*

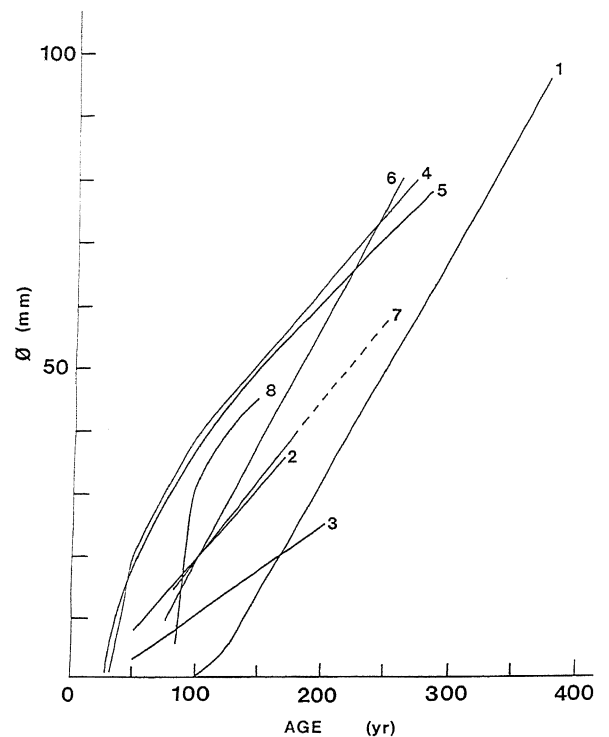


Fig. 1 - Growth curves of *Rhizocarpon geographicum* for the Italian Alps. 1 - Lavaccii and Montandaynè Glaciers (Gran Paradiso National Park) (Beschel, 1958); 2 - Forni Valley (Belloni, 1970); 3 - Solda Valley (Belloni, 1973); 4 - Triolet (Mount Blanc massif) (Porter & Orombelli, 1980); 5 - Forni Valley (Orombelli & Porter, 1983); 6 - Lys Glacier (Monte Rosa) (Strada, 1988); 8 - Lobbia small glacier (Valley of Genova) (Baroni & Carton, 1991b).

Curve di crescita del Rhizocarpon geographicum per le Alpi italiane. 1 - Ghiacciai di Lavaccii e Montandaynè (Parco Nazionale del Gran Paradiso) (Beschel, 1958); 2 - Valle dei Forni (Belloni, 1970); 3 - Valle di Solda (Belloni, 1973); 4 - Triolet (massiccio del Monte Bianco) (Porter & Orombelli, 1980); 5 - Valle dei Forni (Orombelli & Porter, 1983); 6 - Ghiacciaio del Lys (Monte Rosa) (Strada, 1988); 8 - Vedretta della Lobbia (Valle di Genova) (Baroni & Carton, 1991b).

carpon geographicum of Mount Rainier (National Park, Washington, USA); several curves obtained by considering the same species in various localities of the northern hemisphere were compared and noticeable differences among the various growth trends were detected. Porter's lichenometric curves are based on data relative to 125 years and were extrapolated by the author for another 4 to 5 centuries, with an error, as Porter himself specifies, of 20%. Moreover, the author emphasized that under the same climatic conditions, lithologic differences can massively modify the growth of lichens.

Analogous problems were observed while considering other epilithic species which may be used in lichenometry (Brodo, 1973; Innes, 1988).

Currently absolute dating schemes found in literature are based on ratios between the diameter of the thalli of crustose lichens, directly correlated to the speed of growth, and the time which we have summed up in

the following equation:

$$\Delta \varnothing = k v \Delta t \quad (a)$$

where

- \varnothing = lichen diameter
- v = speed of growth
- t = time
- k = parameter representing growth factors
(as listed in chapter 5)

4. A CRITICAL REVISION OF THE LICHENOMETRIC TECHNIQUE: BIOLOGICAL AND METHODOLOGICAL CONSIDERATIONS

Some scholars have critically reviewed the lichenometric method on the basis of biological and methodological considerations that, if overlooked, may condition the reliability of the method (Benedict, 1967; Webber & Andrews eds., 1973a; Jochimsen, 1973; Innes, 1988).

Lichens used are predominantly those with the crustose thallus because characterized by greater longevity (thalli with a diameter of several decimeters may be many centuries old) (Ozenda & Clauzade, 1970; Brodo, 1973). These too, like all lichens in general, are difficult to characterize in field conditions (Roux, 1981). One of the drawbacks in using lichens as a dating instrument derives from the poor lichenological knowledge of some operators. In most lichenometric studies *Rhizocarpon geographicum* is used, probably because it is considered (erroneously) by non-specialists as an easily recognizable species in the field due to its flashy yellow color. Numerous other studies have proved that it is actually a very complex group comprised of many taxa (Jochinsem, 1973; Winchester, 1986; Innes, 1988; Poelt, 1988) characterized by various growth rates. Similar considerations can be made for other species used in lichenometry and belonging mostly to the genera *Aspicilia*, *Lecanora*, *Lecidea* and *Xanthoria*.

Beschel insists on the importance of selecting only circular thalli for measurement. In natural environments this form is very rare, with elliptical or irregular-shaped lichens prevailing. Thus, it is necessary to define parameters which may in some way take such variety into account. Measurements cannot be limited to the diameter alone but must include the larger, the smaller and the average diameter, the area of the thallus (Innes, 1988) and its thickness.

Another element to take into account is the correct identification of the individual thalli us with respect to colonies, which, as it has often occurred in practice, can trick the non-specialist. Furthermore, some scholars have stressed the need to increase the number of measurements in order to reduce the potential effects of the presence of anomalous thalli in sampling (Innes, 1988).

5. PROPOSALS FOR MODIFYING THE LICHENOMETRIC METHODOLOGY: INTRODUCTION OF BIOTIC AND ABIOTIC FACTORS

Extrapolations normally developed in the construction of growth curves using the Beschel method are, in our opinion, excessive.

Generally only some of the factors that may condition the ratio in eq. (a) are taken into consideration, even if each of them, taken individually, may produce slight differences in the actual growth curve. However, since the factors involved in the ratio — indicated by "k" in eq. (a) — interact more or less simultaneously, a realistic growth curve must consider them as parts of a whole.

The list given below was obtained on the basis of our experiments in the field and contains the factors we considered significant from a geological-morphological, ecological and lichenological points of view.

A comparison with publications on lichenology — in particular lichenometry — allowed us to ascertain that:

- 1) some of the factors on our list had already been considered in lichenometric studies in the past, but often only from a qualitative never quantitative perspective, barring few exceptions;
- 2) numerous factors on our list have already been examined and discussed in literature, sometimes on a quantitative basis, but without a specific application to lichenometry;
- 3) some factors appear in literature only as indications or suggestions for further research;
- 4) lastly, some factors had never been considered at all (at least not within the vast bibliography we consulted) and must therefore be completely verified on a lichenometric basis.

The numbers in square brackets refer to works in which each single factor is discussed or cited. Bibliographic indications are given at the bottom of each partial list.

The whole of examined factors was divided into five categories. The first four refer to characters peculiar to lichens, their substratum and environment, whereas the fifth one refers to the standardization of measuring methods, and therefore strictly involves lichenometry.

5.1. Chemical-geological-petrographical factors

- Substratum (meant generically without specifying petrographic and textural peculiarity);
- Chimism of the lithoidal substratum:
 - a) absolute (of the rock) [1];
 - b) mineralogical (of the individual granules in contact with the hyphae of the thalli) [2];
 - c) of the derivative by hydrolysis [3];
- Structure of the lithoidal support [4]: schistosity, stratification etc.;
- Aspect of the natural lithoidal support surface [5]: presence of vacuoles, fissures, granularity, phenomena

- of differentiated alteration, etc.;
- Appearance of anthropic lithoidal support surface: stonework [6], carved slabs or surfaces [7], artificial materials [8];
- Water circulating on the rock surface: direction of flow, stagnant pools, reascent by microcapillarity etc.;
- Mechanical [9], chemical and biochemical [10] alterations of the lithoidal support;
- Colour of the lithoidal support (different drying times in relation to the different surface warning) [11];
- Substratum dip [12];
- Substratum stability [13]

- [1] Belanger (1988), Belloni (1973), Porter (1981), Brodo (1973), Baroni & Carton (1991 b), Jones *et al.* (1980), Carrara & Andrews (1973), Nimis & Monte (1988), Wilson & Mc Hardy *et al.* (1981), Werner (1956)
- [2] Beschel & Weidick (1973), Garty *et al.* (1974), Jones & Wilson (1985), Ottonello *et al.* (1991)
- [3] Schatz (1963), William & Rudolph (1974)
- [4] Ottonello *et al.* (1991), Wetmore (1970)
- [5] Birkeland (1973), Fry (1922, 1924, 1927)
- [6] Modenesi & Lajolo (1988), Nimis & Monte (1988), Piervittori & Sampò (1987-88), Piervittori & Sampò (1988), Piervittori *et al.* (1991), Roccardi & Binchetti (1988), Seaward & Giacobini (1988)
- [7] Carrara & Andrew, (1973), Innes (1988)
- [8] Carrara & Andrew (1973), Garcia *et al.* (1988)
- [9] Birkeland (1973), Fry (1927), Levin (1949), Mahaney (1987), Modenesi & Lajolo (1988), Jones (1988), Pallecchi & Pinna (1978), Syers (1964, 1969), Williams & Rudolph (1974)
- [10] Ascaso *et al.* (1976), Ascaso (1985), Bachman (1907), Gehrman *et al.* (1988), Hallbauer & Jahns (1977), Iskandar & Syers (1971), Jones (1988), Jones & Wilson (1985), Kerr & Zavada (1989), Modenesi & Lajolo (1988), Seaward (1976), Seaward & Giacobini (1988), Wilson & McHardy (1981), Williams & Rudolph (1974)
- [11] McCarthy (1983), Wessel & Budel (1989)
- [12] Gilbert (1984), Gregory (1976), Link & Nash III (1984), Pentecost (1979)
- [13] Innes (1988)

5. 2. Climatic-morphological-geographic factors

- Climate (as reported in a general sense by some authors) [14];
 - a) microclimate (meant as climate of restricted geographical areas with analogous climatic characteristics like temperature, average rainfall etc.) [15];
 - b) submicroclimate (meant as variations of temperature, lighting, humidity on a metric or submetric scale) [16];
- Wind: abrasive action [17], transport and deposition of dust, occlusive action in relation to both lighting and pores, variability of wind direction etc.;

- Temperature variation [18]: daily, monthly and yearly temperature ranges; thermic inversion; formation of valley and mountain breezes etc.;
- Altitude [19];
- Exposition: insolation [20], degree of humidity [21], evaporation rate, degree of lighting [22] etc.;
- Precipitation: average yearly rainfall [23], frequency, intensity, distribution of precipitations [24]; snow cover [25], times of cover, snow blanket aeration, several year-long niveous [26] or glacial cover etc.;
- Latitude.

- [14] Beschel (1958), Hale (1983), Mahaney (1987), Porter (1981), Rydzak (1961)
- [15] Belloni (1970; 1973), Miller (1973), Orombelli & Porter (1983)
- [16] Jochimsen (1973), Miller (1973)
- [17] Frstrup (1951), Juckes (1969), Selby *et al.* (1973)
- [18] Hale (1983), Jochimsen (1973), McCarthy (1983), Wessel & Budel (1989)
- [19] Belloni (1970), Beschel (1958), Orombelli (1987), Orombelli & Porter (1981)
- [20] Belloni (1970, 1973)
- [21] Hale (1983)
- [22] Lange (1965)
- [23] Belloni (1970, 1973), Beschel (1958), Jochimsen (1973)
- [24] Beschel (1958)
- [25] Benedict 1990), Lindsay (1978)
- [26] Benedict (1990)
- [27] Gregory (1976; 1977)

5. 3. Ecological-environmental factors

- Interaction with other organisms: plant and animal parasitism, animal trample, nitrophytism etc. [28]
- Pollution in air and waters circulating [29] on the lithoidal support: acid rain, presence and absorption of toxic metallic ions [30], presence and absorption of radionuclides [31], effect of chemical elements normally considered inert [32] etc.;

- [28] Lawrey (1980; 1984), Seaward & Giacobini (1988)
- [29] Deruelle (1988), Ferry *et al.* (1973), Nash III & Wirth (1988)
- [30] Alessi & Visintin (1988), Lange & Ziegler (1963), Nieboer & Richardson (1980), Purvis (1984), Purvis *et al.* (1987), Rune (1953), Seaward (1964)
- [31] Richardson *et al.* (1985), Tuominen & Jaakkola (1973)
- [32] Seaward (1976).

5. 4. Lichenological factors

- Symbiotic nature of the lichens [33];
- Morphological and ecological variability [34];
- Taxonomic aspects [35];

- Shape and individuality of thalli [36];
- Reproduction and dispersion methods [37];
- Growth and colonization (lichen life cycle patterns) [38];
- Maximum age reached by the species [39].

[33] Ahmadjian (1967), Honegger (1991), Scott (1967; 1973)

[34] Dan Miller (1973), Doppelbauer (1959), Kappen (1973; 1984), Longton (1988), Miller (1973), Purvis (1984), Purvis *et al.* (1987), Seaward (1977)

[35] Benedict (1988), Innes (1988), Hafellner (1988), Poelt (1973, 1988), Winchester (1986)

[36] Innes (1988), Jochimsen (1973)

[37] Bailey (1976), Bowler (1975), Longton (1988)

[38] Armstrong (1973; 1974; 1976), Carrara & Andrews (1973), Hale (1973), Hooker (1980), Miller (1973), Proctor (1977, 1983), Seaward (1976), Ten Brink (1973), Tophman (1977)

[39] Beschel (1958), Brodo (1965), Hale (1970; 1973), Hausman (1948), Miller (1973), Phillips (1963), Proctor (1983).

5. 5. Geometric-mathematical factors

- Instrumentation used (degree of precision, calibration etc.) [40];
- Standardized measuring methods [41];
- Degree of acceptable eccentricity (in the case of slightly elliptic thalli) [42];
- Evaluation of the three-dimensional development of thalli [43]: thalli thickness, thalli volume in relation to the geometric sphere of entanglement etc.;
- Analytical development of the growth curves of thalli [44]: linear and logarithmic curves [45], fractals [46] and chaotic growths.

[40] Belloni (1970), Hale (1973), Innes (1988)

[41] Belloni (1970), Benedict (1988), Beschel (1958), Dale (1985), Farrar (1974), Hakulinen (1966), Hale (1973), Innes (1988), Lindsay (1973), Miller (1973), Pelfini (1988), Proctor (1983), Ten Brink (1973), Webber & Andrew (1973b), Woolhouse (1968)

[42] Hill (1981)

[43] Armstrong (1976), De Marchi & Cassi (1991), Doppelbauer (1959)

[44] Innes (1988)

[45] Armstrong (1973; 1976), Beschel (1973), Dale (1985), Dan Miller (1973), Denton & Karlen (1973), Miller (1973), Orombelli & Porter (1983), Pelfini (1988), Porter & Orombelli (1980), Proctor (1977), Strada (1988)

[46] De Marchi & Cassi (1991).

It is probable that part of the factors cited in the first four categories, interacting amongst themselves, may at times undergo a drastic decrease in their effects on the growth/time system, but this situation has apparently

never been experimented, not even in a local area. Furthermore, we are not certain to have singled out all the biotic and abiotic factors that significantly affect growth. We hope other researchers will evaluate the survey and expand it.

5. 6. The "Zero Time" factor

In our opinion, there is another parameter, deserving more attention, namely the: "zero time" (T). "T" is the moment when the lichen starts to settle down on a lithic surface. The general tendency is to assume that the thallus has the same age as the substratum or that its age has the same order of size of the colonized surface.

This preliminary consideration might lead to anomalous results, sometimes event to gross errors. Only recently have some authors confronted the problem, emphasizing its effect in lichenometric studies (Fahsel *et al.*, 1988).

6. CONCLUSIONS

The method based on the use of lichens as indicators of absolute dating needs to be overhauled in order to provide a model reflecting the real thallus growth in nature, and at the present status of knowledge is worth a global revision in order to make it more reliable from the point of view of applications. This may become possible when the aforementioned factors are quantitatively correlated on the basis of both field observations and experimentally-derived mathematic equations. In other words, from an interdisciplinary point of view comparing data from various disciplines (lichenological, geological, mathematical and physical).

What emerges is that presently lichens are used as a dating tool but only in qualitative way and in local areas. By correlating data from a series of direct observations of various kind, lichens were proven to be suitable means for establishing relative dating sequences. It is presently possible to hypothesize sequences of the type: "first...then...", based on considerations regarding shape and size of the thalli of various species, integrated by both geological-morphological and ecological information, but without quantifying the real duration of the phenomena (Gregory, 1976, 1977; Baroni & Carton, 1987; Gallo, 1992; Piervittori 1990, unpublished data).

Such an interpretation is, in this case, closely linked to the ability of the various researchers to single out the highest possible number of elements in the field and to examine them from the perspective of their own experience and scientific sensitivity.

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REFERENCES

- Ahmadjian V., 1967 - *The Lichen Symbiosis*. Blaisdell Waltham, Mass.
- Ahamadjian V. and Hale M. E. eds., 1973 - *The lichens*. Academic Press, New York, San Francisco, London.
- Alessi P. & Visintin D., 1988 - *Protective agents as a possible substrate for biogenic cycles*. *Studia geobotanica*, **8**, 99-112.
- Armstrong R. A., 1973 - *Seasonal growth and growth rate-colony size relationships in six species of saxicolous lichens*. *New Phytol.* **72**, 1023-1030.
- Armstrong R.A., 1974 - *Growth phases in the life of a lichen thallus*. *New Phytol.* **73**, 913-918.
- Armstrong R.A., 1976 - *Studies on the Growth Rates of Lichens*. In: Brown D. H., Hawksworth D. L. & Bailey R. H. eds. - *Lichenology: Progress and Problems*. Academic Press, London and New York, 309-322.
- Ascaso C., 1985 - *Structural aspects of lichens invading their substrata*. In: Vicente C., Brown D.H., Legaz M.E. eds. - *Surface physiology of Lichens*. Universidad Complutense, Madrid, 87-113.
- Ascaso C., Galvan J. & Ortega C., 1976 - *The pedogenic action of Parmelia conspersa, Rhizocarpon geographicum and Umbilicaria pustulata*. *Lichenologist*, **8**(2), 151-172.
- Backmann E., 1907 - *Die Rhizoidenzone granitbiewohnender Flechten*. *Jb. wis. Bot.*, **44**, 1-40.
- Baroni C. & Carton A., 1987 - *Geomorfologia della valle dell'Avio (Gruppo dell'Adamello)*. *Natura Bresciana Ann. Mus. Civ. Sc. Nat.*, **23**, 1986, 3-47.
- Baroni C. & Carton A., 1991a - *Vedretta di Pisgana (Gruppo dell'Adamello)*. *Geomorfologia e variazioni oloceniche della fronte*. *Natura Bresciana Ann. Mus. Civ. Sc. Nat.*, **26**, 1989, 5-34.
- Baroni C. & Carton A., 1991b - *Variazioni oloceniche della Vedretta della Lobbia (Gruppo dell'Adamello, Alpi Centrali)*. *Geogr. Fis. Dinam. Quat.*, **13**, 1990, 105-119.
- Bailey R.H., 1976 - *Ecological aspects of dispersal and establishment in lichens*. In: Brown D.H., Hawksworth D.L. & Bailey R.H. eds. - *Lichenology: Progress and Problems*. Academic Press, London, 215-247.
- Bowler P.A. & Rundel P.W., 1975 - *Reproductive strategies in lichens*. *Botanical J. of the Linnean Society*, **70**, 325-340.
- Belanger J. R., 1988 - *Prospecting in glaciated terrain: an approach based on geobotany, biogeochemistry, and remote sensing*. *Geol. Serv. Canada*, **387**, 38 pp.
- Belloni S., 1970 - *Nota preliminare sulle ricerche lichenometriche nell'alveo vallivo del Ghiacciaio dei Forni*. *Boll. Com. Glacial. Ital.*, (2), **18**, 43-49.
- Belloni S., 1973 - *Ricerche lichenometriche in Valfurva e nella Valle di Solda*. *Boll. Com. Glaciol. Ital.*, **21**, 19-33.
- Benedict J. B., 1967 - *Recent glacial history of an alpine area in the Colorado Front Range, U.S.A. Establishing a lichen growth curve*. *J. Glaciol.*, **6**, 817-832.
- Benedict J. B., 1988 - *Techniques in lichenometry: identifying the yellow Rhizocarpons*. *Arct. Alp. Res.*, **20**(3), 285-291.
- Benedict J. B., 1990 - *Lichen Mortality due to Late-Lying Snow: results of a Transplant Study*. *Arct. Alp. Res.*, **22**(1), 81-89.
- Beschel R.E., 1950 - *Flechten alls Altermasstab erzenter Moränen*. *Z. Gletscherkd. Gaziolgeol.*, **1**, 152-161.
- Beschel R.E., 1957 - *A project to use lichens as indicators of climate and time*. *Arctic*, **10**(1), 60.
- Beschel R. E., 1958 - *Ricerche lichenometriche sulle morene del gruppo del Gran Paradiso*. *N. Giorn. Bot. Ital.*, **65**, p. 538 & ff.
- Beschel R.E., 1961 - *Dating rock surfaces by lichen growth and its application to glaciology and physiography (lichenometry)*. In: Raasch G.O. ed. - *Geology of the Arctic*. Univ. Toronto Press, Toronto, **2**, 1044-1062.
- Beschel R. E., 1973 - *Lichens as measure of the age of recent moraines*. *Arct. Alp. Res.*, **5**(4), 303-309.
- Beschel R. E. & Weidick A., 1973 - *Geobotanical and Geomorphological Reconnaissance in West Greenland, 1961*. *Arct. Alp. Res.*, **5**(4), 311-319.
- Birkeland P. W., 1973 - *Use of Relative Age Dating Methods in a Stratigraphic Study of Rock Glacier Deposits, Mt. Sopris, Colorado*. *Arct. Alp. Res.*, **5**(4), 401-416.
- Boyle A. P., McCarthy P. M. & Stewart D., 1987 - *Geochemical control of saxicolous lichen communities on the Creggaun Gabbro, Letterfrack, Co. Galway, western Ireland*. *Lichenologist* **19**(3), 307-317.
- Brodo I. M., 1965 - *Studies on growth rates of corticolous lichens on Long Island, New York*. *Bryologist*, **68**, 451-456.
- Brodo I. M., 1973 - *Substrate Ecology*. In: Ahamadjian V. & Hale M. E. - *The Lichens*. Academic Press, New York, San Francisco, London, 401-441.
- Brown D. H. ed., 1985 - *Lichen Physiology and Cell Biology*. Plenum Press, New York and London, 362 pp.
- Brown D. H., Hawksworth D. L. & Bailey R. H. eds., 1976 - *Lichenology: Progress and Problems*. Academic Press, London, New York and San Francisco.
- Hale M. E. eds. - *The Lichens*. Academic Press, New York, 401-441.
- Carrara P. E. & Andrews J. T., 1973 - *Problems and Application of Lichenometry to Geomorphic Studies, San Juan Mountains, Colorado*. *Arct. Alp. Res.*, **5**(4), 373-384.
- Dale M. R. T., 1985 - *A geometric techniques for evaluating lichen growth models using the boundaries of*

- competing lichen thalli*. Lichenologist, **17**(2), 141-148.
- Dan Miller C., 1973 - *Chronology of Neoglacial Deposits in the Northern Sawatch Range, Colorado*. Arct. Alp. Res., **5**(4), 385-400.
- De Marchi A. & Cassi, 1992 - *Modelli matematici di colonizzazione lichenica ottenuti mediante l'esame di equazioni frattali*. Not. Soc. Lich. Ital., **5**, 84.
- Denton G. H. & Karlen W., 1973 - *Lichenometry: Its Application to Holocene Moraine Studies in Southern Alaska and Swedish Lapland*. Arct. Alp. Res., **5**(4), 347-372.
- Deruelle S., 1988 - *Effets de la pollution atmospherique sur la végétation lichenique des monuments historiques*. Studia Geobotanica, **8**, 23-31.
- Doppelbauer H., 1959 - *Studien zur Anatomie und Entwicklungsgeschichte einiger endolithischen pyrenocarpen Flechten*. Planta, **53**, 223-230.
- Fahselt D., Maycock P. & Svoboda J., 1988 - *Initial establishment of saxicolous lichens following recent glacial recession in Sverdrup Pass, Ellesmere Island, Canada*. Lichenologist, **20**(3), 253-268.
- Farrar J. F., 1974 - *A method for investigating lichen growth rates and succession*. Lichenologist, **6**(2), 151-157.
- Ferry B.W., Baddeley M.S. & Hawksworth D.L., 1973 - *Air Pollution and Lichens*. Athlone press, London, 389 pp.
- Fischer P. J. & Proctor M. C. F., 1978 - *Observations on a season's growth in Parmelia caperata and P. sulcata in South Devon*. Lichenologist **10**(1), 81-89.
- Fristrup B., 1951 - *Wind erosion in the Arctic deserts*. Geogr. Tids., **52**, 51-65.
- Fry E. J., 1922 - *Some types of endolithic lichens*. Ann. Bot. London, **36**, 541-562.
- Fry E. J., 1924 - *A suggested explanation of the mechanical action of lithophytic lichens on rocks (shale)*. Ann. Bot. London, **38**, 175-196.
- Fry E. J., 1927 - *The mechanical action of crustaceous lichens on substrata of shale, schist, gneiss, limestone and obsidiane*. Ann. Bot. London, **41**, 437-460.
- Gallo L. M., 1992 - *Problemi metodologici connessi all'impiego delle tecniche lichenometriche*. Not. Soc. Lich. Ital., **5**, 84.
- Galun M. ed., 1988 - *The Handbook of Lichenology*. CRC Press, Boca Raton, Florida, 3 voll.
- Garcia Rowe J. & Saiz Jimenez C., 1988 - *Colonization of mosaics by lichens: the case study of Italica (Spain)*. Studia Geobotanica, **8**, 65-71.
- Garty J., Gal M. & Galun M., 1974 - *The relationship between physicochemical soil properties and substrate choice of "multisubstrate" lichen species*. Lichenologist, **6**(2), 146-150.
- Gehrmann C., Krumbein W. E. & Petersen K., 1988 - *Lichen weathering activities on mineral and rock surfaces*. Studia Geobotanica, **8**, 33-45.
- Gilbert O. L., 1984 - *Lichens of the magnesium limestone*. Lichenologist **16**(1), 31-43.
- Gregory K. J., 1976 - *Lichen and the determination of river channel capacity*. Earth Surface Processes, **1**, 273-285.
- Gregory K. J., 1977 - *Stream network volume: An index of channel morphometry*. Geol. Soc. Am. Bull., **88**, 1075-1080.
- Hakulinen R., 1966 - *Über die Wachstumsgeschwindigkeit einiger Laubflechten*. Ann. Bot. Fenn., **3**, 167-179.
- Hale M. E., 1970 - *Single-Lobe growth rate patterns in the lichen Parmelia caperata*. Bryologist, **73**, 72-?.
- Hale M. E., 1973 - *Growth*. In Ahamadjian V. & Hale M. E. eds. - *The Lichens*. Academic Press, New York, San Francisco, London, 473-492.
- Hale M. E., 1983 - *The Biology of Lichens*. 3rd ed. London, Edward Arnold, 190 pp.
- Hallabuer D. K. & Jahns H. M., 1977 - *Attack of lichens on quartzitic rock surfaces*. Lichenologist, **9**(2), 119-122.
- Hausman E. H., 1948 - *Measurements of the annual growth-rate of two species of rock lichens*. Bull. Torrey Bot. Club, **75**, 116-117.
- Hawksworth D. L. & Hill D. J. 19...(?) *The lichen-forming Fungi*. Blackie, USA: Chapman & Hall, New York.
- Hill D. J., 1981 - *The growth of lichens with special reference to the modelling of circular thalli*. Lichenologist **13**(3), 265-289.
- Hill D. J., 1984 - *Studies on the growth of lichens. I: Lobe formation and the maintenance of circularity in crustose species*. Lichenologist, **16**(3), 273-278.
- Honegger R., 1991 - *Functional aspects of the lichen symbiosis*. Annu. Rev. Plant Physiol. Plant Moll. Biol., **42**, 553-578.
- Hooker T. N., 1980 - *Lobe growth and marginal zonation in crustose lichens*. Lichenologist **12**(3), 313-325.
- Hooker T. N. & Brown D. H., 1977 - *A photographic method for accurately measuring the growth of crustose and foliose saxicolous lichens*. Lichenologist, **9**(1), 65-75.
- Innes J. L., 1988 - *The Use of Lichens in Dating*. In Galun M. ed. - *Handbook of Lichenology*. CRC Press, Boca Raton, Florida, III: 75-91.
- Iskandar I. K. & Syers J. K., 1971 - *Solubility of lichen compounds in water: Pedogenetic implications*. Lichenologist, **5**(1/2), 45-50.
- Jochimsen M., 1973 - *Does the Size of Lichen Thalli Really Constitute a Valid Measure for Dating Glacial Deposits ?*. Arct. Alp. Res., **5**(4), 417-424.
- Jones D., 1988 - *Lichens and Pedogenesis*. In: Galun M. ed., 1988 - *Handbook of Lichenology*. CRC Press, Boca Raton, Florida, III: 109-124.
- Jones D. & Wilson M. J., 1985 - *Chemical activity of lichens on mineral surfaces: a review*. International Biodeterioration, **21**(2), 99-104.
- Jones D., Wilson M. J. & Tait J. M., 1980 - *Weathering of a basalt by Pertusaria corallina*. Lichenologist

- 12(3), 277-290.
- Juckles L. M., 1969 - *Weathering hollows in charnockite at Mannefaulknaussane, Dronning Maud Land*. Brit. Antarct. Surv. Bull., **22**, 97-98.
- Kappen L., 1973 - *Responses to extreme environments*. In: Ahamadjian V. & Hale M. E. eds. - *The Lichens*. Academic Press, New York, San Francisco, London, 310-380.
- Kappen L., 1984 - *Ecological aspects of exploitation of the non-living resources of the Antarctic continent*. In: Wolfrum R. ed. - *Antarctic Challenge*. Duncker & Humblot, Berlin, 211-217.
- Kerr S. & Zavada M.S., 1989 - *The effect of the Lichen *Acarospora sinopica* on the Elemental Composition of three Sedimentary Rock Substrates in South-Africa*. The Bryologist, **92**(3), 407-410.
- Kershaw K. A., 1984 - *Physiological Ecology of Lichens*. Cambridge University Press, Cambridge.
- Lange O. L., 1965 - *Der CO₂- Gaswechsel von Flechten bei tiefen temperaturen*. Planta, **64**, 1-19.
- Lange O.L. & Ziegler H., 1963 - *Der Schwermetallgehalt von Flechten aus dem *Acarosporium sinopicae* auf Erzschlackenhal den des Harzes. 1. Eisen und Kupfer*. Mitt. Flor.-soz. Arb. Gemein., N.F. **10**, 156-183.
- Lawrey J.D., 1984 - *Biology of Lichenized Fungi*. Praeger, New York, 408 pp.
- Levin F. M., 1949 - *The role of lichens in the weathering of limestone and diorites*. Vertin. Mosk. Gos. Univ., **9**, 149-159.
- Lindsay D. C., 1973 - *Estimates of lichen growth rates in the maritime Antarctic*. Arct. Alp. Res., **5**(4), 341-346.
- Lindsay D. C., 1978 - *The Role of Lichens in Antarctic Ecosystems*. Bryologist, **81**(2), 268-276.
- Link S.O. & Nash III T.H., 1984 - *An Analysis of an Arctic Lichen Community with respect to Slope on Silicious Rocks at Anaktuvuk Pass, Alaska*. The Bryologist, **87**(2), 162-166.
- Longton R.E., 1988 - *Biology of polar bryophytes and lichens*. Cambridge University Press, 391 pp.
- Hafellner J., 1988 - *Principles of classification and main taxonomic groups*. In: Galun M. ed. - *Handbook of Lichenology*. CRC Press, Boca Raton, Florida, III, 41-52.
- Mahaney W. C., 1987 - *Lichen trelines and weathering features as indicators of mass balance changes and successive retreat stages of the Mer de Glace in the Western Alps*. Z. Geomorph. N. F., **31**(4), 411-418.
- McCarthy P. M., 1983 - *The composition of some calcicolous lichen communities in the Burren, western Ireland*. Lichenologist, **15**(3), 231-248.
- Miller G. H., 1973 - *Variations in Lichen Growth from Direct Measurements: Preliminary Curves for *Alectoria minuscula* from Eastern Baffin Island, N.W.T., Canada*. Arct. Alp. Res., **5**(4), 333-339.
- Modenesi P. & Lajolo L., 1988 - *Microscopical investigation on a marble encrusting lichen*. Studia Geobotanica, **8**, 47-64.
- Nash III T.H. & Wirth V., 1988 - *Lichens, Bryophytes and Air Quality*. Cramer, Berlin, Stuttgart, 297 pp.
- Nieboer E. & Richardson D.H.S., 1980 - *The replacement of the nondescript term "heavy metals" by a biologically and chemically significant classification of metal ions*. Environmental Pollution series B, **1**, 3-26.
- Nimis P. L. & Monte M., 1988 - *The lichen vegetation on the Cathedral of Orvieto (Central Italy)*. Studia Geobotanica **8**, 77-88.
- Nimis P.L., Pinna D. & Salvadori S., 1992 - *Licheni e conservazione dei monumenti*. CLUEB, Bologna, 170 pp.
- Orombelli G., 1987 - *Le spiagge emerse oloceniche di Baia Terra Nova (Terra Vittoria, Antartide)*. Atti Acc. Lincei Rend. fis. (8), **81**, 403-416.
- Orombelli G. & Porter S. C., 1983 - *Lichen growth curves for the southern flank of the Mount Blanc Massif, Western Italian Alps*. Arct. Alp. Res., **15**, 193-200.
- Otonello D., Alaimo R., Calderone S. & Montana G., 1991 - *Contributo alla conoscenza del rapporto tra i licheni e i substrati litici*. Giorn. Bot. Ital., **25**(3), 263.
- Pallecchi P. & Pinna D., 1988 - *Azione della crescita sulla pietra nell'Area Archeologica di Fiesole*. Studia Geobotanica, **8**, 113-124.
- Ozenda P. & Clauzade G., 1970 - *Les Lichens. Etude biologique et flore illustrée*. Masson et Cie., Paris, 801 pp.
- Pelfini M., 1988 - *Contributo alla conoscenza delle flut-tuazioni oloceniche del Ghiacciaio dei Forni (Gruppo Ortles-Cevedale, Sondrio)*. Natura Bresciana Ann. Mus. Civ. Sc. Nat. Brescia, **24** (1987), 237-257.
- Pentecost A., 1979 - *Aspect and slope preferences in a saxicolous lichen community*. Lichenologist, **11**(1), 81-83.
- Phillips H. C., 1963 - *Growth rate of *Parmelia isidiosa* (Müll. Arg.) Hale*. J. Tenn. Acad. Sci., **38**, 95-96.
- Piervittori R. & Sampò S., 1987/88 - *Colonizzazione lichenica su manufatti litici: la facciata dell'Abbazia di Vezzolano, Asti (Piemonte)*. Allionia, **28**, 93-102.
- Piervittori R. & Sampò S., 1988 - *Lichen colonization on stoneworks: examples from Piedmont and Aosta Valley*. Studia Geobotanica, **8**, 73-75.
- Piervittori R., Laccisaglia A., Appolonia L., Gallo L.M., 1991 - *Aspetti floristico-vegetazionali e metodologici relativi a licheni su materiali lapidei in Valle d'Aosta*. Rev. Valdôtaine Hist. Nat., **45**, 53-86.
- Poelt J., 1973 - *Classification*. In: Ahamadjian V. & Hale M. E. eds. - *The Lichens*. Academic Press, New York, San Francisco, London, 599-632.
- Poelt J., 1988 - *Rhizocarpon *Ram. em. Th. Fr. subgen. Rhizocarpon in Europe**. Arct. Alp. Res., **20**(3), 292-298.
- Porter S. C., 1981 - *Lichenometric studies in the Cascade Range of Washington: establishment of Rhizocarpon geographicum growth curves at Mount*

- Rainier. Arct. Alp. Res., **13**(1), 11-23.
- Porter S. C. & Orombelli G., 1980 - *Catastrophic rockfall of September 12, 1717 on the Italian flank of the Mont Blanc*. Z. Geomorph. N. F., **24**(2), 200-218.
- Proctor M. C. F., 1977 - *The growth curve of the crustose lichen Buellia canescens (Dicks)*. De Not. New Phytol., **79**, 659-663.
- Proctor M. C. F., 1983 - *Sizes and growth-rates of thalli of the lichen Rhizocarpon geographicum on the moraines of the Glacier de Valsorey, Valais, Switzerland*. Lichenologist, **15**(3), 249-262.
- Purvis O. W., 1984 - *The occurrence of copper oxalate in lichens growing on copper sulphide-bearing rocks in Scandinavia*. Lichenologist, **16**(2), 197-204.
- Purvis O. W., Elix J. A. Broomhead J. A. & Jones G. C., 1987 - *The occurrence of copper-norstickic acid in lichens from cupriferous substrata*. Lichenologist **19**(3), 193-203.
- Richardson D.H.S., Kiang S., Ahmadjian V. & Nieboer E., 1985 - *Lead and uranium uptake by lichens*. In: Brown D.H. - *Lichen physiology and cell Biology*. Plenum Press, New York and London, 227-246.
- Roccardi A. & Bianchetti P., 1988 - *The distribution of lichens on stoneworks in the surroundings of Rome*. Studia Geobotanica, **8**, 89-97.
- Roux C., 1981 - *Etude Ecologique et Phytosociologique des Peuplements Licheniques Saxicoles-Calcicoles du Sud-Est de la France*. Cramer, Vaduz, 557 pp.
- Rune O., 1953 - *Plant life on serpentines and related rocks in the north of Sweden*. Acta, Phytogeogr. Suec., **31**, 1-139.
- Rydzak J., 1961 - *Investigation on the growth rate of lichens*. Annls. Univ. Mariae Curie-Sklodovska, C, **16**, 1-15.
- Schatz A., 1963 - *Soil Microorganisms and Soil Chelation. The Pedogenic Action of Lichens and Lichen Acids*. Agric. Food Chem., **11**, 112-118.
- Scott G. D., 1967 - *Studies of the lichen symbiosis: 3. The water relations of lichens on granite kopjes in central Africa*. Lichenologist, **3**(3), 368-385.
- Scott G.D., 1973 - *Evolutionary Aspects of Symbiosis*. In: Ahmadjian V. & Hale M. E. eds. - *The Lichens*. Academic Press, New York, San Francisco, London, 581-598.
- Seaward M. R. D., 1964 - *Some observation on heavy metal toxicity and tolerance in lichens*. Lichenologist, **6**(2), 158-164.
- Seaward M. R. D., 1976 - *Performance of Lecanora muralis in an Urban Environment*. In: Brown D. H., Hawksworth D. L. & Bailey R. H. eds. - *Lichenology: Progress and Problems*. Academic Press, London and New York, 323-357.
- Seaward M.R.D. ed., 1977 - *Lichen Ecology*. Academic Press, London San Francisco, New York, 550 pp.
- Seaward M. R. D. & Giacobini C., 1988 - *Lichen-induced biodeterioration of Italian monuments, frescoes and other archaeological materials*. Studia Geobotanica, **8**, 3-11.
- Selby M. J., Palmer R. W. D. & Smith C. J. R., 1973 - *Ventifact distributions and wind directions in Victoria Valley, Antarctica*. N. Z. Jour. Geol. Geophys., **16**, 303-306.
- Smith A. L., 1921 - *Lichens*. Cambridge University Press, Cambridge.
- Strada E., 1988 - *Le variazioni del Ghiacciaio del Lys dalla "piccola glaciazione" ai nostri giorni*. Natura Bresciana Ann. Mus. Civ. Sc. Nat., Brescia, **24** (1987), 275-288.
- Syers J. K., 1964 - *A study of soil formation on carboniferous limestone with particular reference to lichens as pedogenetic agents*. Ph. D. Thesis, University of Durham, England.
- Syers J.K., 1969 - *Chelating ability of fumarprotocetraric acid and Parmelia conspersa*. Plant Soil, **31**, 205.
- Ten Brink N. W. (1973 - *Lichen Growth Rates in West Greenland*. Arct. Alp. Res., **5**(4), 323-331.
- Webber P. J. & Andrews J. T. eds., 1973a - *Lichenometry: dedicated to the memory of the Late Roland E. Beschel*. Arct. Alp. Res., **5**(4), 293-432.
- Tohpmann P.B., 1977 - *Colonization, Growth, Succession and Competition*. In: Seaward M.R.D. - *Lichen Ecology*. Academic Press, London, 31-68.
- Tuominen Y. & Jaakkola T., 1973 - *Absorption and accumulation of mineral elements and radioactive nuclides*. In: Ahmadjian V. & Hale M.E. - *The Lichens*. Academic Press, New York, San Francisco, London, 185-223
- Webber P. J. & Andrews J. T., 1973b - *Lichenometry: a Commentary*. Arct. Alp. Res., **5**(4), 295-302.
- Werner R.G., 1956 - *Etudes écologiques sur les lichens des terrains schisteaux maritimes*. Bull. Sci. Nancy (N. S.) **15**, 137-152.
- Wessel D.C.J. & Budel B., 1989 - *A rock pool Lichen communities in Northern Transvaal, South Africa: composition and distribution patterns*. Lichenologist, **21**(3), 259-277.
- Wetmore C.M., 1970 - *The lichen family Heppiaceae in North America*. Ann. Mo. Bot. Gard., **57**, 158-209.
- Wilson M. J. & MC Hardy W. J., 1981 - *The weathering of Serpentinite by Lecanora atra*. Lichenologist, **18**, 167-176.
- Williams M. E. & Rudolph E.D., 1974 - *The role of lichens and associated fungi in the chemical weathering of rock*. Micologia, **66**, 648-660.
- Winchester V., 1986 - *A tabular key to yellow Rhizocarpon species identified so far in the British Isles*. British Lichen Society, 58 summer, 23-25.
- Woolhouse H. W., 1968 - *The measurements of growth rates in lichens*. Lichenologist, **4**(1), 32-33.

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