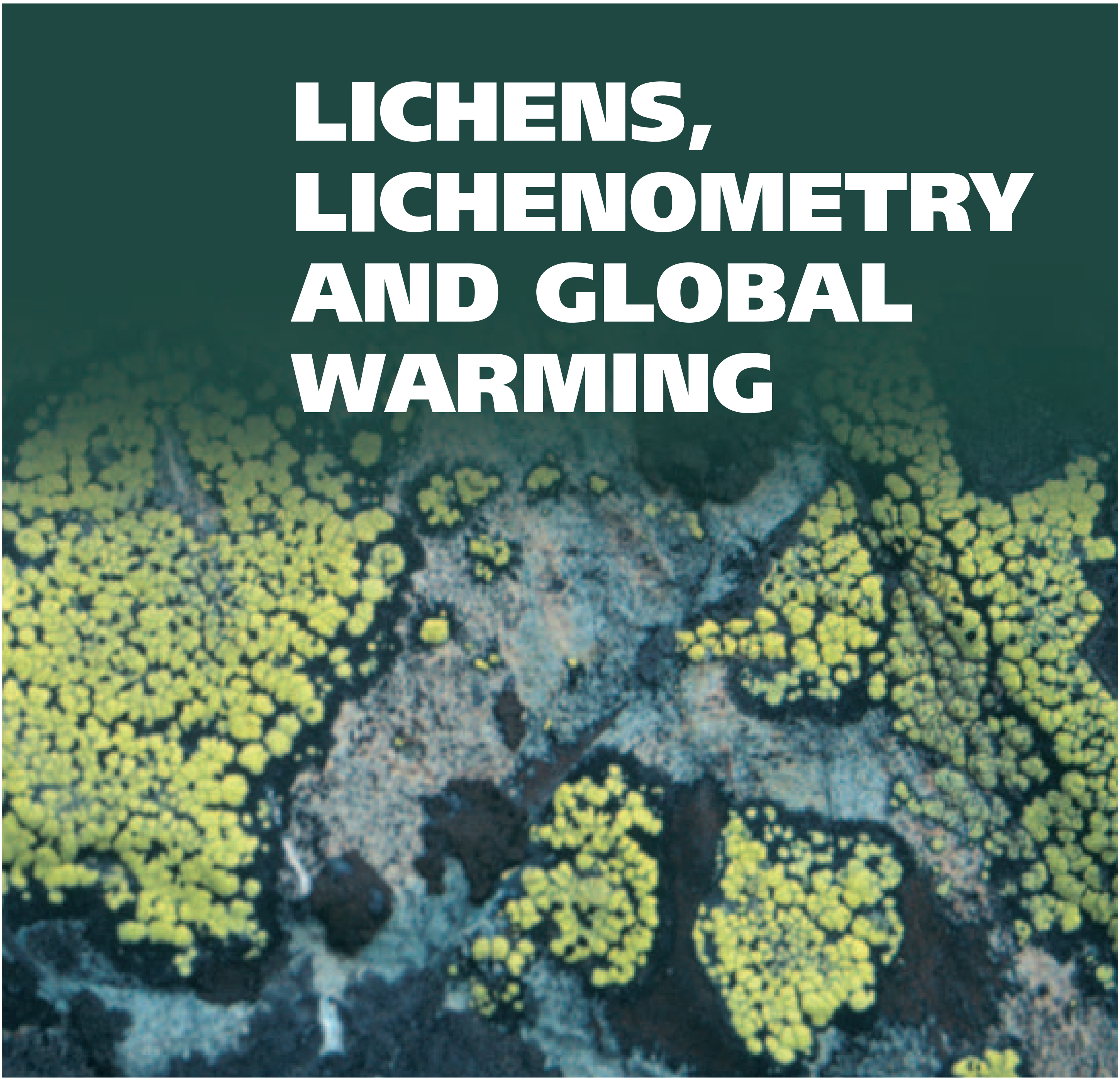
Richard Armstrong describes an alternative method of dating

LICHENS, LICHENOMETRY AND GLOBAL WARMING



GEOLOGICAL AND climatic history share common themes with history, politics, and many other disciplines, that of the need to establish a timescale of events. In pre-history, timescales are critical to understanding evolution of biological, tectonic, and climatic systems that have interacted to produce the contemporary surface of the Earth. Many chronological tools have emerged to allow elapsed time to be accurately estimated for timescales ranging from decades to millions of years.

One of the most widely used techniques is 'Lichenometry', the use of symbiotic fungi in the form of lichens, growing on rock surfaces or other suitable substrates, to obtain an approximate date of the deposition of the surface. This article describes the methodology of lichenometry, the usefulness of the method in dating surfaces over the last 500 years, a period in which radiocarbon dating is relatively inefficient, and discusses how the technique has contributed to the debate over climatic change and global warming.

Lichens

Lichens are very common organisms on Earth and are found in a range of environments including the surfaces of rocks, trees, and man-made structures. A lichen is an intimate association between two quite different microorganisms, *viz.*, an alga and a fungus resulting in a

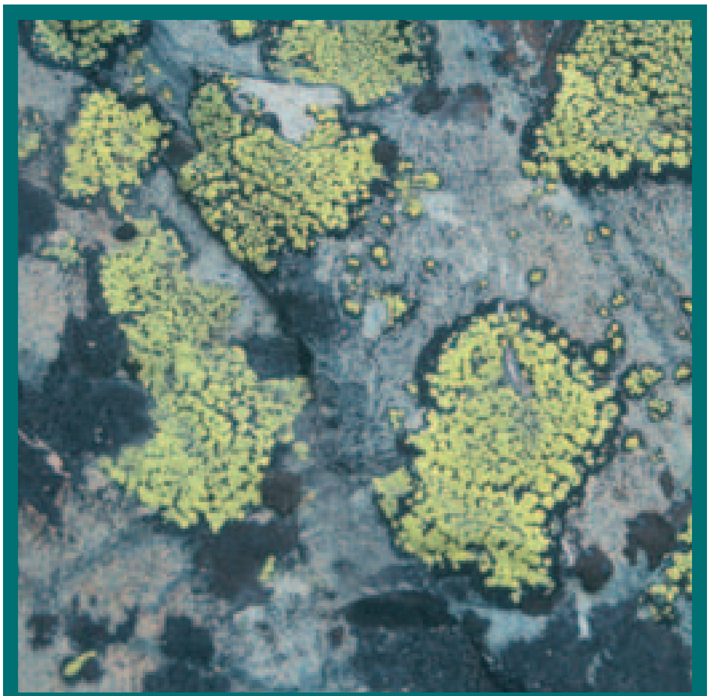


Fig. 1: *A population of yellow-green thalli of the lichen Rhizocarpon geographicum on scree boulders in the Pacific Northwest, USA. The yellow-green islands of areolae can be clearly seen as well as the black fungal hypothallus at the margin.*

'macroorganism', the lichen thallus, the morphology of which is quite unlike that of the two original constituents. The two organisms are so intimately associated that the term mutualism or symbiosis has been applied to it. Lichens were the first examples of symbiosis in which translocation between the constituent symbionts was demonstrated especially the movement of carbohydrate from the algae to the fungus. It is possible that the fungus supplies the algae with low concentrations of nutrients or vitamins but this translocation has not been convincingly demonstrated. A fuller description of lichen growth and physiology is given in a previous article in the *Microbiologist* (Armstrong, 2003, Vol 4, No.4).

There are three major types of lichen, *viz.*, the fruticose type in which the lichen thallus is attached to the substratum at a single point and forms a complex branched structure, the foliose type that comprises a series of radially arranged leaf-like lobes, and the crustose type that is tightly attached to the substratum. The foliose and crustose types of lichen grow radially over the substratum rather like a fungus on an agar plate but growth rates are very slow. Many foliose species have rates of radial extension between 2 and 5 mm per year but many crustose lichens grow much more slowly with rates of less than 0.5 mm per year. Some species grow so slowly that larger thalli growing in the Arctic may live to be over 5000 years old, thus making them candidates for oldest organism on Earth. It is this slow growth and the longevity of crustose lichens that have made them especially useful in lichenometry (Innes, 1985).

Lichenometry

Lichenometry depends on the assumption that if the lag time before colonisation of a substratum by a lichen is known and the growth of the lichen can be measured, then a minimum date can be obtained by measuring the diameter (or another property related to size) of the largest lichen at the site. The method is particularly useful in regions above and beyond the tree-line and especially in Arctic-Alpine environments where lichens grow very slowly and have great longevity. In such environments, it is possible to date deposits up to thousands of years old but, in the majority of cases, the method is most useful for dating over the past 500 years.

The 'Rhizocarpon' group of lichens

The majority of lichenometric studies have been conducted using a specific group of crustose lichens, viz., the yellow-green species of the genus *Rhizocarpon* (Fig. 1). This type of lichen is abundant in many Arctic-Alpine environments, grows very slowly (0.02 – 2 mm yr^{-1}), and lives to a considerable age. Morphologically, the lichen comprises discreet areolae that contain the cells of the alga *Trebouxia*, located on a fungal medulla which is attached to the substratum and which extends into a black algal-free marginal zone around the thallus called the hypothallus (Armstrong & Smith 1987). Within each areola there is a cortical layer 15-80 mm thick, an algal layer, and medullary tissue. The fungal hypothallus extends radially and to grow, relies on carbohydrate supplied from the areolae (Armstrong & Smith, 1987). Primary areolae near the edge of the hypothallus may develop from free-living algal cells on the substratum that are trapped by the hypothallus while secondary areolae may develop from zoospores produced within the thallus.

Different species of *Rhizocarpon* may colonise a surface at different rates, e.g., species of the section *Rhizocarpon* may colonise earlier than the species *Rhizocarpon alpicola*. However, *R. alpicola* grows faster than most members of the section *Rhizocarpon* and eventually becomes the largest lichen on the substratum (Innes, 1985).

Measurements

Several measurements of lichen thallus size have been suggested as the most useful in lichenometric studies. The use of the 'largest inscribed circle', i.e., the largest circle that can be drawn within an individual thallus was suggested by Locke *et. al.*, (1979) and has been adopted by several workers and is equivalent to using the 'shortest diameter' of the thallus. By contrast, many workers have suggested that it is the largest diameter of the thallus is the most appropriate measure. A major drawback of this method, however, is that individual lichen thalli can fuse together and therefore, be recorded as a single thallus (Armstrong, 1984). Other workers have averaged the longest and shortest axes or used both measurements to derive estimates of the surface area of the thallus (Griffey, 1977). In addition, various sampling methods have been employed. Either the single largest thallus at the site is measured and regarded as representative of age (Webber & Andrews 1973) or several of the largest deposits present are averaged (e.g., Mathews, 1974). Some workers have used the frequency distribution of thallus size as an indicator of the age of the substratum but the problem of using such distributions for dating is that they can be interpreted in several different ways (Innes, 1985).

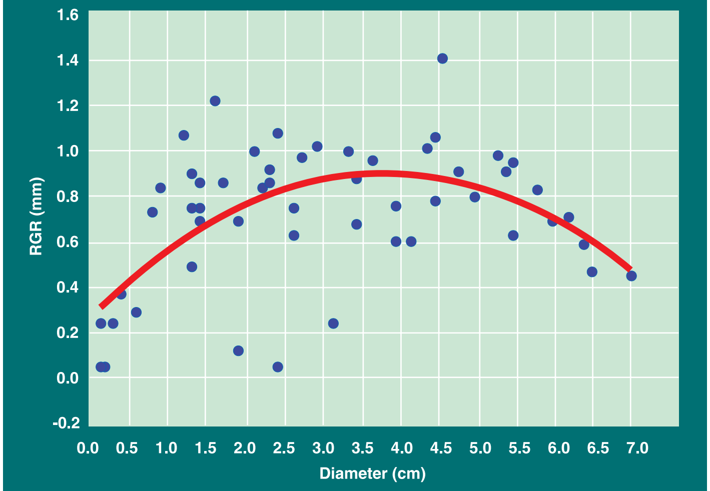


Fig. 2: *The growth curve of the lichen Rhizocarpon geographicum determined by direct measurement. A plot of radial growth rate (RGR) versus thallus diameter on rock surfaces in north Wales.*

Establishing a lichen growth curve

A lichen growth curve for an area can be established by two methods. First, directly by measuring the radial growth rate of the lichen over a period of time or indirectly, by measuring the diameter of lichen thalli on surfaces of known age. The indirect method is regarded as the most useful since it integrates' the effects of climatic change on lichen growth over long periods. By contrast, direct measurements relate only to the rates of growth over a particular, usually short, period of time. An example of the growth curve of the lichen *Rhizocarpon geographicum* obtained by direct measurement is shown in Fig 2. The growth curve appears to be non-linear, an early phase of increasing growth reaching a maximum in thalli about 2.5 – 4.5 cm diameter and then a phase of declining growth.

A variety of sources can provide information for dating a substratum and establishing a growth curve including gravestones, mine spoil heaps, abandoned farms or houses, and stone-walls or cairns. In addition, natural deposits can be used that have been dated accurately from historical events, radiocarbon dating, or the use of tree growth rings (dendrochronology). An example of a lichen growth curve relating lichen size and age derived in southeast Iceland is shown in Fig. 3 (Bradwell, 2001). This growth curve is also non-linear in shape. The relationship is often described best by a third-order polynomial function and which describes the declining growth rate apparent in larger and therefore, older thalli, also a feature of the growth curve derived by direct measurement. This is a feature of many *Rhizocarpon* growth curves and could be due to thallus senescence (Armstrong, 1983). Another possibility is that the curve reflects a tendency for more rapid growth to have occurred in the last 100 years, i.e., environmental change over the last 300 years could have accounted for variations in lichen growth over time.

There are many uncertainties in lichenometric studies resulting from a lack of knowledge of fundamental lichen biology (Worsley, 1981). For example, there are limited data on the nature of lichen colonisation and on the influence of environmental factors on lichen growth rates. Moreover, there is a lack of reproducibility of many sampling designs, unresolved questions relating to the adequacy of using thallus diameter as an index of age, and many other difficulties associated with the methodology (Innes, 1985). Despite these problems, lichenometry, in combination with other methods, has proved to be an extremely valuable tool in dating the surfaces of deposits.

Applications of lichenometry

Lichenometry has been used in many different contexts to date surfaces. The dating of the sequences of rocks forming glacial moraines has been the most widely used application. Porter (1981) working on the moraines of Mount Rainier in Washington State, USA, (Fig. 4) used historical evidence for the past marginal positions of the glaciers and buildings together with other structures in the National Park to provide surfaces of known age from 1857 to the present. The single largest circular *Rhizocarpon geographicum* thallus was used as a measure of lichen growth. The study indicated that the moraine probably stabilised four years earlier than had been suggested by other studies.

Other applications of lichenometry including the dating of the stone images on Easter Island, stone-walls in England, river flooding, sea-level changes, and the occurrence of landslides (Innes, 1985).

Climatic change

During the last 25 years, there has been increasing concern as to the impact of possible climatic change and especially global warming due to the 'greenhouse effect'. Lichenometric studies have played an important role in this debate in providing data that support global warming. McCarroll (1993) used the size frequency distribution of lichen populations to determine the ages of boulders resulting from avalanches in south Norway. Snow avalanches reflect periods of high winter snow and rapid spring melting rather than low temperatures. It was concluded that increasing avalanche activity in south Norway was attributable to the greenhouse effect. Harrison and Winchester (2000) using a combination of lichenometry and dendrochronology studied the 19th and 20th century fluctuations of glaciers in south Chile. There was evidence for retreat of the glaciers following the 'little ice age' maximum between 1850 and 1880. Glacier retreat increased during the 1940s and the degree of synchrony exhibited by different glaciers has suggested a common climatic influence. This pattern has been repeated around the world. In central Asia, there were some small advances of the glaciers during 1908-11, 1911-34 and 1960-77 (Narama, 2002). However, significant recession also occurred in the 1900s especially in 1911-34 and 1977-78. Recession then accelerated after 1990 reflecting recent climatic

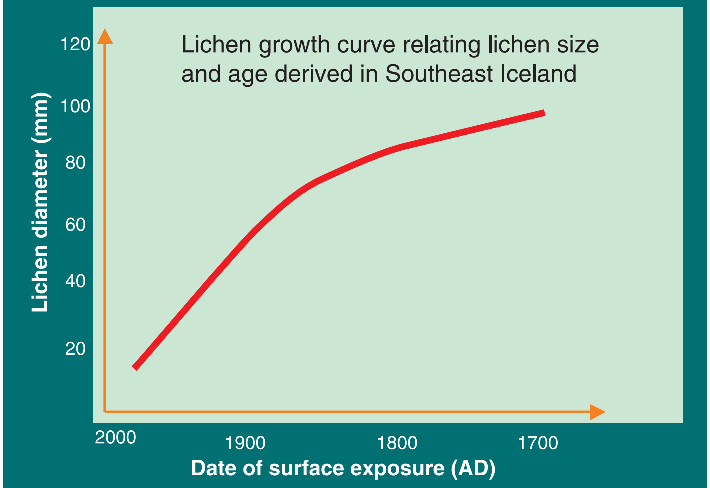


Fig 3: *A growth curve of the lichen Rhizocarpon geographicum from southeast Iceland determined by lichenometry. The non-linear form of the curve is a notable feature of lichen growth curves from many sites around the globe.*

Fig 4: *The terminal moraine of Emmons glacier, Mount Rainier, Washington State, USA. The boulders deposited by the retreating glacier are clearly visible and after a certain lag time become colonised by crustose lichens.*

warming in inland Asia. Records of glacier fluctuation are now compiled by the World Glacier Monitoring service and have derived estimates of global warming during the last 100 years (Oerlemans, 1994). Examination of data from all over the world has confirmed that the retreat of glaciers has occurred over the globe and can be explained by a linear warming trend of 0.66 Kelvin per century (Oerlemans, 1994).

Conclusions

Lichenometry is one of many techniques now available for estimating the elapsed time since the exposure of a substratum. Its advantages include an ability to date surfaces during the last 500 years, a time interval in which radiocarbon dating is least efficient, and provides a quick, cheap, and relatively accurate date for a substratum. Nevertheless, there are many problems associated with the methodology (Innes, 1985) with some authors (e.g. McCarthy, 1999) concluding that because of suspect methodology, most lichenometric ages are not in fact verifiably accurate. Improvements in methodology, the adoption of careful sampling regimes, and increased knowledge of the ecology of lichens are likely to improve accuracy and reliability in future (Innes, 1985). Lichenometry, together with complimentary techniques, is likely to continue to play an important role in dating a variety of surfaces and therefore in providing data that contribute to the debate regarding climatic change and global warming.

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