The University of Aston in Birmingham

ASSESSING AIR POLLUTION

IN

THE BLACKBROOK VALLEY

by

Catherine Fiona Wilson

Submitted for the Degree of Master of Philosophy

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SUMMARY

This thesis describes methods for assessing air pollution levels in the Blackbrook Valley, near Dudley in the West Midlands. The research forms part of a long-term environmental monitoring programme coordinated by the Nature Conservancy Council.

Literature is examined on the methods used to obtain air pollution data, in particular, the compilation of an emission or sources inventory. Although the purpose-collection of emission inventory data and direct measurement of ambient air concentrations are reported to be the most exact methods, these were found to be cost-prohibitive. Alternative methods of data collection, e.g. by calculation were considered.

A biological method, using lichen boards to monitor the pollution-induced colour changes in *Hypogymnia physodes*, was examined in detail. A methodology for this approach was developed from the literature and a survey was implemented in the winter of 1983/84. The results obtained justified the adoption of the basic methodology and suggested a number of modifications to the practical survey procedures. A more extensive survey was undertaken in the winter of 1984/85. Improvements to the board design and recording procedures permitted more detailed observations of lichen damage than were obtained for the first survey.

The survey results revealed significant, and widely varying, differences in the levels of lichen damage throughout the Blackbrook Valley. These differences could not be explained in terms of known geographical and meteorological data for the area. Both surveys showed the same mean level of lichen damage. The data obtained provides a basis for future comparative assessment of air pollution in the Blackbrook Valley.

The lichen board technique, as described, provides a simple and inexpensive method for measuring relative pollution levels, which could be employed for periodic or occasional surveys.

KEY WORDS: AIR POLLUTION, BIOLOGICAL INDICATION, LICHEN BOARD BLACKBROOK VALLEY.

To my parents

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CHAPTER 1

THE RESEARCH BACKGROUND

CONTENTS:

1.0.0 OUTLINE

The research described in this thesis forms part of the Blackbrook Valley Project, which is a long term environmental planning and management study of the Blackbrook Valley, near Dudley in the West Midlands. It was conducted within the Interdisciplinary Higher Degree (IHD) Scheme at Aston University, in collaboration with the Nature Conservancy Council.

The purpose of this chapter is to provide information on

a) the origins of the IHD study and the context of this work within the Blackbrook Valley Project, and
b) the role of the sponsoring organisation (the Nature Conservancy Council) and the objectives of the research.

The structure of the thesis is also presented.

1.1.0 INTRODUCTION: THE ORIGINS OF THE IHD STUDY

In 1980 the Council of Europe launched a campaign, called the Campaign for Urban Renaissance, to promote the improvement of life in towns. The intention of the campaign was to stimulate public awareness of, and encourage participation in, the management of the urban environment.

In response to this initiative the Nature Conservancy Council and the Landscape Institute, together with the Council for Environmental Conservation put forward a proposal to set up a project in the West Midlands. The intention was to find a site and

> "to attempt an experimental approach where the best techniques of environmental improvement could be used within the framework of full community involvement."(1)

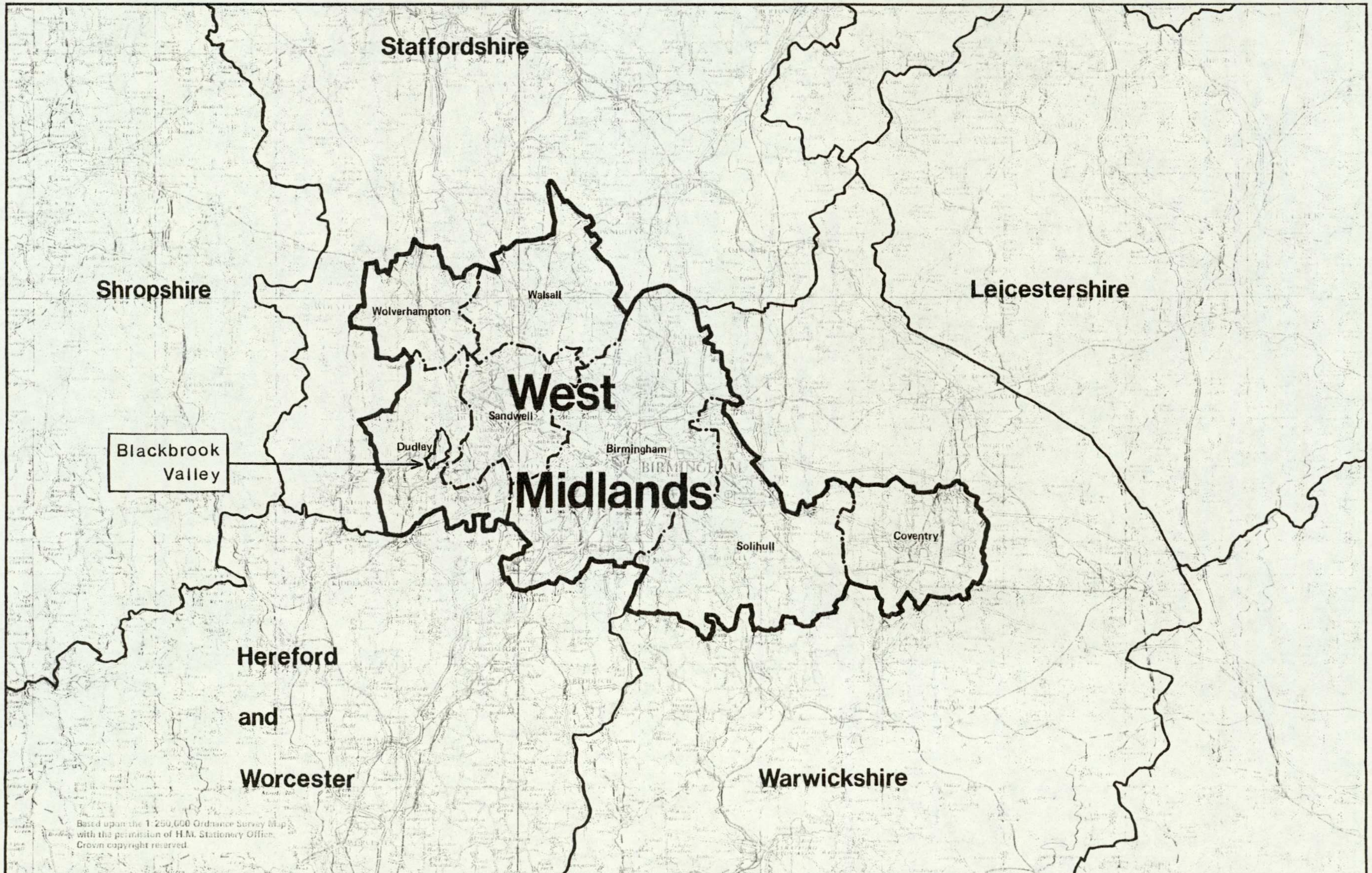
The site would contain a representative selection of the serious environmental problems found in the West Midlands and elsewhere and would therefore be a demonstration case for other urban areas.

The idea for the project was taken up by Dudley Metropolitan Borough Council (Dudley MBC) with the support of the West Midlands County Council and the Department of the Environment. The site proposed for the "experimental approach" was the Blackbrook Valley. Several factors contributed to the suitability of this choice. In 1980 the West Midlands County Council published the West Midlands County Structure Plan(2), outlining its proposed strategy for the development of the County in the 1980's. A principal aim of this strategy was "regeneration of the older urban areas to improve the overall quality of life".(3) In order to concentrate efforts to relieve environmental, economic and social problems, the County Council had identified certain

Priority Areas. These were the areas "with large numbers of houses in unsatisfactory condition, industrial dereliction, decaying shopping centres and large amounts of derelict waste land." They also had "related socio-economic problems including high levels of unemployment".[4] The Blackbrook Valley was included as a Priority Area in the Structure Plan.

The launch of the Urban Renaissance Campaign in 1980 therefore coincided with the development of plans for the area. Detailed land use policies, prepared by Dudley MBC, had already been approved by the West Midlands County Council. In addition, the western part of the valley was being considered for designation as an Enterprise Zone. The idea of the Urban Renaissance project was not incompatible with these proposals and, in fact, would enable a coordinated approach to planning and monitoring of the various activities. The Blackbrook Valley was selected as the site for the Urban Renaissance project.

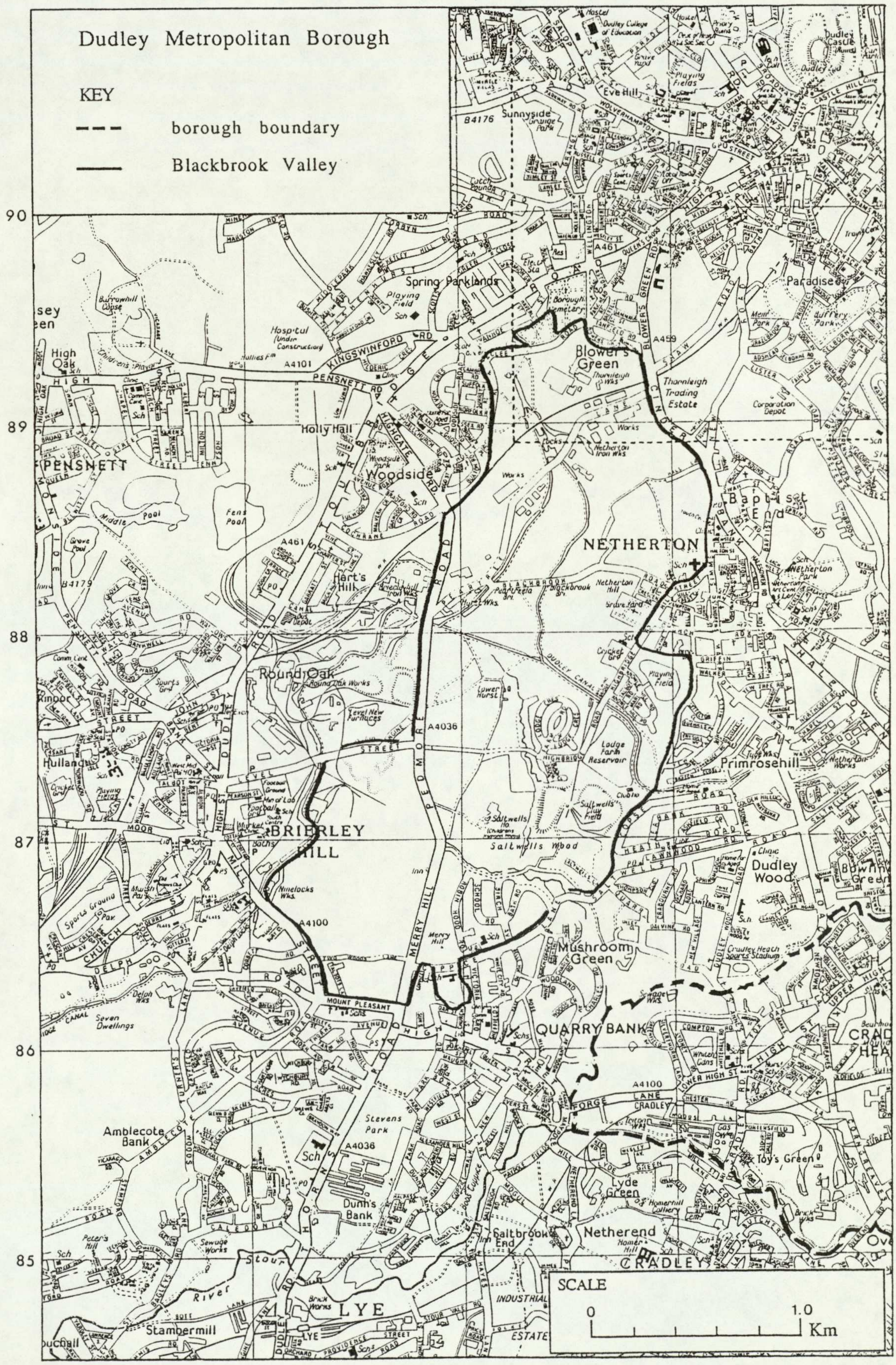
Fig. 1.1 Map of the West Midlands County, showing location of the Blackbrook Valley.



Source: West Midlands County Council

Fig. 1.2 Map of the Blackbrook Valley showing detail of the study area.

Source: Dudley Metropolitan Borough Council



1.2.0 BLACKBROOK VALLEY

1.2.1 Geographical and historical background

The Blackbrook Valley is situated south west of Dudley Town Centre, between the old industrial communities of Brierley Hill and Netherton (see map, Fig. 1.2). In the past this has been an area of intense industrial activity. The geology of the region, which provides the key to this, is comprehensively described in the Memoirs of the Geological Survey of England and Wales.[5] A basic and more readable account can be found in the Saltwells Wood Geology and Trail Guide.[6]

The Blackbrook Valley is underlain by sedimentary rocks from the Triassic, Carboniferous and Silurian periods. Of these, the Carboniferous rocks are the most important in the history of the area. These are made up of a variety of deposits belonging to the Middle Coal Measures, which form part of the South Staffordshire Coalfield. These include sandstones, mudstones and shales, seams of coal, fireclay and ironstone. It is these deposits which gave rise to the manufacturing industries of the Black Country. In the late eighteenth and nineteenth centuries coal and other minerals were extracted to supply the needs of many industrial activities. The Blackbrook Valley was particularly noted for metal working and associated trades, including the manufacture of steel. It also provided a large proportion of the raw materials for industries in neighbouring areas, including the glass manufacturing industry at Stourbridge. These activities peaked in importance in the middle of the nineteenth century. Towards the end of this century, in common with other former centres of the Industrial Revolution, the Blackbrook Valley fell into decline. Many of the raw materials had been worked out. Also, as new industrial processes were adopted, the old areas were abandoned.

1.2.2 Recent history: the need for redevelopment

In 1974 in the Dudley Structure Plan[7] the local authority recognised the underuse of land in the Blackbrook Valley and its potential as a major area for satisfying the housing and industrial development needs of the Borough. Figures for landuse in 1976[8] showed that there were 174 ha of vacant land in the Blackbrook Valley, of which half could be classified as officially derelict.

As a result of the proposals of the West Midlands County Council Structure Plan, described earlier, a new development plan was required for the Blackbrook Valley. In 1981 a study was carried out by Dudley Metropolitan Borough Council to identify the problems of the valley and to examine the feasibility of development plans for the area. The findings of this study were documented in the report "Blackbrook Valley Development: Feasibility Study 1981".[9]

Lack of redevelopment in the Blackbrook Valley was the result of the poor ground conditions left by earlier industrial activities. In the above study Dudley Council summarised this situation as follows:

> "The Blackbrook Valley represents a major land resource within Dudley which has remained largely undeveloped, not because of negative planning measures, but because of the physical difficulties of bringing forward the land for beneficial use."[10]

The study examined in detail the physical constraints on development. The past history of mining activities was considered to be a major cause of difficulties. In all seven aspects of significance were listed, namely

1. underground mining
2. opencast mining
3. clay extraction
4. tips
5. environment
6. drainage
7. access

Underground mining. This had been the main form of mining on the west side of the valley. The depth of mining at different sites varied from near ground level down to 500 feet. The major problems resulting from these mines included pit shafts (over 170 recorded), adits, collapsed pit excavations and poor load bearing capacities of spoil heaps. With suitable reinstatement much of the land was potentially satisfactory for industrial redevelopment. However, the report stated that each site would require careful assessment of conditions to determine the "economic viability" of development.

Opencast mining. This is the oldest form of mining known in the Blackbrook Valley. Coal was reputedly dug out of the hillsides in the fourteenth century.[11] The main area where outcropping occurs is along the west side of the Netherton Anticline, which runs from Netherton Hill south west to the centre of the valley. The hillside to the west of Netherton Church was still being mined by the National Coal Board (NCB) in the early 1960's. Subsequent restoration of the area by the NCB was carried out in a highly unsatisfactory manner. According to the Council's report the ground was left in a poorly consolidated condition and was consequently "incapable of supporting built development".[12] Today opencast mining is being carried out in the area between Pedmore Road and Lodge Farm. Technically the operation is a land stabilisation exercise (with coal extraction as an incidental operation), forming part of the development of the Enterprise Zone. In practice it has the same effect as opencast mining for coal. The work, begun in February 1983, is now virtually completed and the land is scheduled to be released for development.

<u>Clay extraction.</u> Like mining this had left problems of poor ground stability, though not on the same scale. The main extraction of clay was from Doulton's Clay Pit (also known as Saltwells Clay Field, see map reference 937872 Fig. 1.2).

<u>Tips.</u> Tipping contributed considerably to the physical deterioration of the area. Old tips were generally uncontrolled and contained unconsolidated or toxic materials, often both. The problem of toxic tipping was complicated further by modern industry, notably the waste products of iron and steel manufacture.

<u>Environment.</u> In addition to the purely physical difficulties affecting development of land in the Blackbrook Valley the Feasibility Study highlighted the importance of sympathetic environmental management. The Feasibility report states:

> "At present the Blackbrook Valley, despite the dereliction, provides a semi-rural outlook which would surprise the casual visitor to the Black Country. It is important to maintain this impression whilst having regard to the obvious need to provide land for industrial development and housing in the area."(13)

A number of industrial sites in the eastern part of the Blackbrook Valley, although officially derelict, had acquired high landscape or conservation value. These included the area of Saltwells Wood and nearby Doulton's Clay Pit. In any development plans these areas would require to be protected.

From the above observations it was clear that the major problem in the development of land in the Blackbrook Valley would be the technical difficulties and high capital cost of the groundwork resulting from instability and toxicity. Of the remaining physical constraints previously listed, namely drainage and access, the Feasibility Study made it clear that the cost of improving these would also be borne by the developers. There were other financial burdens. In particular Land Development Tax, the tax levied on the difference in land value before and after development, was a major disincentive to potential developers.

1.2.3 Dudley Enterprise Zone

In March 1980 the new Conservative Government announced proposals to set up a scheme which was "intended to pioneer a new, and more adventurous, approach to the whole question of industrial and commercial renewal".(14) This was to be by means of so-called "enterprise zones". The aim of the Enterprise Zone Scheme was to reduce regulatory controls and provide certain tax incentives to encourage industrial development in the designated enterprise zone areas.

In May 1980 Dudley Local Authority submitted an application to the Central Government for the western part of the Blackbrook Valley to be considered as an enterprise zone, in order that relaxations on planning and industrial development regulations, together with various financial benefits, would provide the necessary incentive to developers to come into the area and undertake restoration of the land for industrial use. The application was successful and approval was granted in June 1981. In 1984 the Enterprise Zone was extended to include the site of Round Oak Steel Works, which closed in December 1982.

The planning requirements which applied in the Dudley Enterprise Zone were described in the Council's document "Dudley Enterprise Zone Planning Scheme".[15] Under these requirements certain types of development were completely excluded from the area of the zone e.g. those involving hazardous substances. The main simplification of the planning regulations was the introduction of a general planning consent which removed the need for new developments to have individual planning permission. The minimum conditions required by new developments covered by this scheme were the standard essential regulations covering health and safety, and pollution emissions. Providing that a proposed development complied with these minimum conditions no specific planning permission would be required. Depending on the intended location of the new development other specific conditions and development exclusions would apply. For this purpose, the Dudley Enterprise Zone was divided into three sub zones. The zones are

sub zone 1 (area covered by general conditions of the Enterprise Zone)
sub zone 2 (sensitive boundaries sub zone)
sub zone 3 (Parkhead Locks, Merry Hill and Mill Street sub zone)

Further details of the sub zones, and of the planning regulations, are in Appendix A.

The idea of a "general" planning consent had obvious disadvantages. The purpose of the above zoning was to try to ensure compatibility of interests in adjacent developments and also to permit some control over the impact of development on the surrounding areas.

1.2.4 Public open space

As outlined in section 1.2.2, the east of the Blackbrook Valley was known to contain areas with unstable ground, which were unsuitable for large scale development. It also contained a number of ecologically sensitive sites, including Saltwells Wood and Doulton's Clay Pit. In the Blackbrook Valley Development Plans most of this area was designated as public open space. Apart from providing the area with a recreational benefit, this was intended to serve as a buffer zone between the developing industry on the west and the existing areas of housing on the east of the valley. With the need for major economic and industrial renewal in the Blackbrook Valley, there was potential for adverse effects on the remaining natural and semi-natural landscapes, particularly resulting from the development of the Enterprise Zone. The presence of the buffer zone would reduce the visual and physical impact on the remainder of the valley and protect the sensitive areas in it.

1.2.5 The significance of the Saltwells Wood area

In September 1981 a Local Nature Reserve was declared on approximately 40 hectares of land, including Saltwells Wood and the nearby site of Doulton's Clay Pit. The reserve was the first Local Nature Reserve to be declared in the West Midlands County.

Saltwells Wood is one of the few remaining areas of woodland of the former Pensnett Chase. Today it contains stands of mature woodland derived mainly from the planting of trees in 1795. The Clay Pit contains a range of vegetation types resulting from natural colonisation of the abandoned excavations. It has a rock face with a 30m exposure of the Middle Coal Measures. Before the designation of the Local Nature Reserve it was already a Site of Special Scientific Interest of international significance among geologists. In a vegetation survey of the area Shimwell[16] identified at least six types of woodland vegetation in Saltwells Wood and a further five types in the clayfield area.

In the future these areas are likely to be the best remaining representation of natural or semi-natural habitats in the Blackbrook Valley. Other areas of significance have already been destroyed e.g. Merry Hill Farm, which was sold in 1984 for industrial redevelopment. Apart from the local value of such semi-rural landscapes in a built-up area, the combined Saltwells Wood and Clayfield area is considered by the Nature Conservancy Council to be one of the most important sites for conservation in the West Midlands County.

In the Blackbrook Valley there is a need to protect sensitive areas such as Saltwells Wood. At the same time there is a social and economic necessity to maximise redevelopment of derelict land. This situation underlines the importance of a research and environmental monitoring programme to coordinate activities which are potentially in conflict. The aims of the Blackbrook Valley Project and development of this programme are described in the next section.

1.3.0 BLACKBROOK VALLEY (URBAN RENAISSANCE) PROJECT

1.3.1 Aims

From the outset it was intended that the Blackbrook Valley Project should be "a broad-based approach to urban regeneration, rather than concentrating on a single site."[17]

At an early stage in the formulation of the Blackbrook Valley Project a project team was set up to define the objectives and future development of the study. In addition to the Nature Conservancy Council and Landscape Institute this team comprised representatives of the key departments of the Dudley Metropolitan Borough Council (e.g. Departments of Planning and Environmental Health), together with representatives of the West Midlands County Council, the Countryside Commission and local landowners.

The objectives of the Blackbrook Valley Project were agreed as follows[18]

1. To conserve and enhance the existing landscape and drainage in the Valley.

2. To minimise the impact of development/redevelopment on the ecology of the Valley by identifying and protecting areas of special natural importance and by taking ecological principles into account in design and management in the Valley as a whole.

3. To ensure that management proposals for the Valley are defined in the context of the design of landscape treatments.

4. To encourage the use of the area as an educational resource.

5. To use the landscaping, survey and environmental monitoring work in the Valley as a vehicle for increasing community involvement in decision making self-help and long term management.

The purpose of the project team was to act as a steering committee. It was seen as "having a coordinating role as an advisory body on environmental works and the impact of proposed development on the landscape."(19) The organisation and implementation of the project would rely on the existing planning and development bodies. Much of the practical work and the necessary academic research would draw on a wide spectrum of outside expertise including local naturalists and schools, university scientists, and professionals from a variety of organisations. The continuing development of the project would be discussed and monitored by the steering committee, which would meet monthly at the Council House in Dudley. The committee currently meets five or six times a year.

1.3.2 IHD involvement

To develop and manage the Blackbrook Valley Project a programme of environmental surveying and monitoring was formulated. This programme was essential, both in the initial stages of the project to obtain the necessary background data, and in the longer term to enable assessment of the project in terms of the broad aims previously outlined. The Nature Conservancy Council (NCC) has the responsibility of stimulating and coordinating the programme of work involved.

Within the environmental surveying and monitoring programme, the present research arose from the need for information on pollution and its possible effects on the ecology of the Blackbrook Valley. The NCC contacted Aston University for advice on obtaining air pollution data. Following this request, the possibility of employing a full-time postgraduate was explored. The present research was successfully launched, in cooperation with the Interdisciplinary Higher Degree (IHD) Scheme at Aston University, in the autumn of 1982. The supervisory team for this research included representatives of the NCC (George Barker) and Dudley MBC (David Spurrier). Further details of the IHD Scheme can be found in Cochran.[20]

1.3.3 Project brief

In Autumn 1982 the Blackbrook Valley Project was two years old. Work which had already been carried out, mainly by short term contract researchers employed by the Nature Conservancy Council, was aimed at building up the required background data, particularly on the natural history of the area.

From the point of view of the NCC there were broadly three aims of an air pollution research programme.

1. To acquire a baseline store of data on existing levels of air pollutants, to be added to the accumulating store of knowledge of the Blackbrook Valley project area.

2. To monitor long term changes in air pollution resulting from development of the Blackbrook Valley, with the aim of monitoring effects on pathways of pollutants in the area, particularly accumulation of pollutants in biological organisms.

3. To assess the implications of the above and to contribute the relevant information to the monitoring processes of future management and planning proposals.

These aims, which were agreed at an early supervisory meeting, formed the starting point for determining the themes of the IHD research.

1.4.0 DEVELOPMENT OF THE RESEARCH OBJECTIVES

1.4.1 Defining the problem

The first stage in the present study was to define in more clear terms the specific aspects of the air pollution problem which were of interest to the NCC. This would enable identification of the areas which could be tackled in an IHD study and, thereby, lead to a workable definition of the objectives of the research.

According to Seinfeld[21] the air pollution problem can be simply depicted as a system consisting of the following basic components.

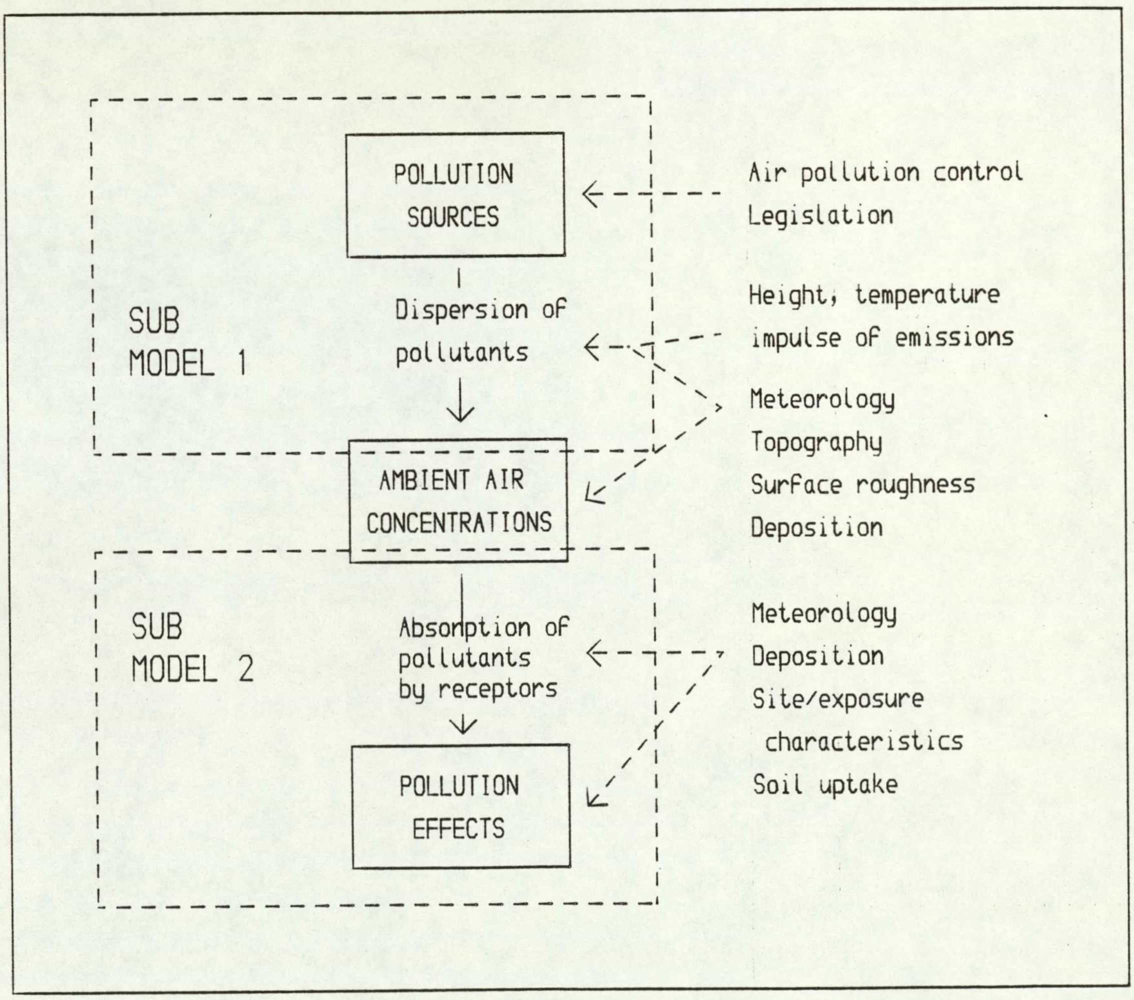
```
        1                          2                         3

Emission sources ------------> Atmosphere ------------> Receptors
                  pollutants              mixing and
                                           chemical
                                        transformation
```

The above events are interdependent. Thus knowledge of pollution sources and the factors governing dispersion of emissions can, by means of an appropriate model, be used to determine ambient concentrations (and *vice versa*). Similarly models can be developed to relate ambient concentrations with effects on receptors. The relationships between these components are shown in Fig. 1.3.

From the aims outlined in the project brief (section 1.3.3) it can be seen that, ultimately, the main concern of the NCC is for information on the absorption of air pollutants by receptors. Specifically the information required will enable the NCC to predict, assess and/or monitor the effects of air pollution and possible control measures on

Fig. 1.3 Basic model of an air pollution system showing source-effect relationships and the influence of some other factors.



Source: adapted from Knabe[13], page 59.

biological organisms in the Valley. In order to be able to link such effects with air quality in the study area, using suitable models as outlined in Fig. 1.3, the NCC requires knowledge of air pollution sources and/or ambient air concentrations.

Measurements of air pollution concentrations are of particular interest to the NCC. These would provide the means to assess environmental quality directly. Information on environmental quality would be required for studies on ecological effects, from which recommendations concerning planning/management of the Blackbrook Valley could be made. Information on pollution sources and emissions is also important. Firstly, as already described, it can be used with an appropriate model to obtain air concentration data. Secondly, data on sources can usefully supplement directly obtained measurements of air concentrations. Thirdly, as with air concentration data, information on sources would form the basis for making planning decisions. In the event of a specific pollution problem or adverse effects of pollution, the NCC would be concerned with identifying the sources responsible for emissions, and the quantities of pollutant emissions involved. This information would be required to enable the NCC to advise the local authority (in this case Dudley MBC) in decisions regarding appropriate corrective action. Ways of obtaining data for the above purposes are now considered.

1.4.2 Obtaining pollution sources and emissions data

Initial discussions with the supervisory team indicated that the compilation of an emission inventory would be a useful means of obtaining data on pollution sources for the Blackbrook Valley.

The use of emission inventory data is a well known approach in environmental monitoring work, particularly in environmental impact assessment and in the formulation and implementation of air pollution legislation. The advantages of using an emission inventory are:

a) The convenience of a standardised format. Once a method for compiling an inventory has been established it is relatively simple to incorporate future collection of data and updating of information into routine procedures.
b) Information from an inventory is also in a readily accessible form, which would provide a convenient starting point for related research work, for example in this study on the ecological effects of pollution.

There are two approaches to obtaining the data required for emission inventories, namely

a) to use purpose-collected data, or
b) to use available information.

Purpose-collected data. This forms the ideal basis for an emission inventory, as the data can be compiled exactly according to the requirements of the survey/programme for which the inventory is required.

Available information. A wide range of data is collected by governmental and other organisations. This kind of information is complementary to purpose-collected data, both to fill in gaps in information and as a means of cross checking calculations based on collected data.

The disadvantage of the inventory approach is that the specific problem, or problems, to be solved would normally require to be defined in advance. The proposed use of the pollution data from an emission inventory determines the way in which the data is collected and compiled.

1.4.3 Obtaining air concentration data

The collection of data on air pollution concentrations can be approached in two ways. It can be obtained either

a) directly, typically by chemical or physical measurement of concentrations, or

b) indirectly, by calculating concentrations from the relevant data on sources and emissions.

Both approaches were considered.

Direct measurement. From the outset of the IHD project it was clear that the collection of data by means of conventional monitoring equipment would be limited. The supervisory team considered that the cost of setting up and maintaining a sufficient number of measuring devices was too high. The possibility of finding cheaper methods of measurement would be the only way of obtaining large amounts of data at first hand. For this purpose the use of biological monitors was a promising approach, which the NCC was keen to explore.

Calculation of concentrations. The ability to calculate airborne pollutant concentrations is dependent on the availability of relevant information on sources and emissions, factors which affect dispersion and on the use of appropriate models.

1.4.4 Summary

From the aims outlined in the project brief it can be seen that the Nature Conservancy Council is primarily interested in monitoring levels of air pollutants in order to obtain the necessary information to determine possible effects on wildlife or habitats. To assess such effects, baseline data is required on emission sources or ambient air concentrations, or both. At the outset of the present research this information was not available for the Blackbrook Valley. The practical difficulties and cost of measuring ambient air concentrations directly were recognised. An important aspect of the research was therefore to look at less expensive or indirect ways of assessing concentrations and/or predicting these. Two main approaches were identified. One approach was the use of biological indicators. The second approach was to calculate concentrations from data on sources and emissions. For the latter an emission inventory would be required. Ways of collecting the necessary data were considered. The purpose-collection of pollution data forms the ideal basis for an emission inventory. This would be accepted as essential in large-scale programmes. Urban areas in Great Britain where such programmes have been carried out include London, Leeds and the Forth Valley.[22,23,24] However, for the reasons of cost outlined in section 1.4.3, the purpose-collection of data would not be possible in the present research. The compilation of a data-base, if attempted, would instead rely mainly on existing data sources, supplemented by field work. In this respect the IHD supervisory team considered that the present study represented a realistic exercise in urban planning and management.

In addition to the above approaches, discussions with the IHD supervisory team indicated that modelling would be a desirable objective in the present research. It would provide the means of linking information on sources, ambient air concentrations and, ultimately, pollution effects. Modelling could be used in two ways. Firstly, it could be used as a means of estimating the existing air pollution concentrations. This would provide the reference data on which to base future monitoring work. Secondly, modelling could be used predictively. Two main types of application were envisaged, namely:

1. It could be used with existing, i.e. known, information to estimate future trends in air pollution concentrations.
2. Alternatively it could be used to assess the consequences of hypothetical situations for which data could not be realistically obtained, either because of lack of resources or because of the risk of undesirable effects.

The benefit of both the above applications is that problems and possible solutions to problems could be explored in advance, giving the basis for using the model as a management tool.

Preliminary examination of the Nature Conservancy Council aims, with respect to air pollution, led to the identification of the following themes:

1. Compilation of an emission inventory. As a method of obtaining information on pollution sources and emissions.
2. Inexpensive methods of data collection. In particular to look at the use of biological monitors as a means of obtaining data on ambient air concentrations.
3. Modelling. As a means of linking information on sources (inventory data) and ambient concentrations, and as a means of predicting pollution levels for management or other purposes.

1.5.0 THESIS OUTLINE

Chapter 1 describes the background to the IHD research and the theoretical framework which was developed. Three aspects were identified (section 1.4.4). The research work undertaken in the first year of the IHD project examined these aspects. The following two chapters provide accounts of the assessments made:

Chapter 2 emission inventory, and dispersion modelling.

Chapter 3 biological indicators.

The results of the above assessments provided the basis for the final research proposals. Following the First Annual Review meeting of the IHD supervisory team in November 1983, it was decided that the main research effort should focus on the examination of biological indicators (lichens) as an inexpensive means of collecting air concentration data. The work subsequently carried out is reported in Chapters 4 and 5:

Chapter 4 Lichen Board Survey 1983/4

Chapter 5 Lichen Board Survey 1984/5

The final chapter (Chapter 6) evaluates the research and presents the thesis conclusions.

PRELIMINARY RESEARCH

CHAPTER 2

DEVELOPMENT OF RESEARCH OBJECTIVES (Part 1)

CONTENTS:

2.0.0 OUTLINE

As described in Chapter 1, a useful model of an air pollution system was identified consisting of the 3 linked components:

pollution sources

ambient air concentrations

pollution effects

There were two main requirements of the present research. Firstly was the need to acquire information on existing pollution levels/sources, to give a baseline record for comparison with future data. The use of an emission inventory and biological indicators were identified as possible methods of compiling such information. Secondly, was the need to have a means of relating the above data on pollution levels/sources to air quality distribution. The use of dispersion modelling would fulfill this requirement.

This chapter examines the emission inventory and dispersion modelling approaches. The literature shows that these are complementary and, if adopted in the Blackbrook Valley research, would require to be developed together.

2.1.0 THE USE OF AN EMISSION INVENTORY

2.1.1 Definition

An emission inventory is basically a set of information on sources and emissions of air pollutants. The World Health Organisation[1] gives the following definition:

> Emission inventory. The compilation of data, either by measurement or (more usually) by estimation, from which a more or less detailed map of the distribution of emissions over a given area may be constructed, showing the positions of the more important sources and the amounts they emit, and the areas in which smaller emitters are concentrated, with the emission per unit area for each. Also called *emission survey* and *source inventory*.

The items of information in the inventory should provide a more or less complete description of the air pollutant emissions for the area or region of interest. Hence an emission inventory can be an effective tool in the study of air pollution and in air pollution management. Since the compilation of an emission inventory can also involve considerable effort and resources it was necessary to assess whether it would be a feasible and appropriate choice for use in the present research in the Blackbrook Valley. The aim of the following sections is to present an assessment of the emission inventory as a potential management tool for this purpose. Two aspects needed to be considered.

1. The purpose of the information in the inventory. This would determine what data was required.
2. How the data would be be collected. This would determine the resources (e.g. finance and manpower) required to set up, operate and update the system.

These aspects are discussed in the following sections, 2.1.2 and 2.1.3.

2.1.2 The purpose of the emission inventory

The proposed use of an emission inventory not only determines the type of information required but also the quality of information, namely (a) the amount of detail (resolution) and (b) the amount of accuracy required in the data. To be useful an inventory also requires to be kept up to date. This allows changes in air quality to be taken into account, and also enables the effectiveness of any control measures based on the inventory to be monitored. Hence a further factor influenced by the proposed use of the inventory is (c) the frequency of updating required. This is dependent on factors (a) and (b) above. Weber has provided a comprehensive account of the construction and management of emission inventories.(2) The method, by which an emission inventory is compiled and maintained, he terms the "emission inventory system". It will usually include procedures for the collection, checking, storage, and retrieval of information. The elements of the emission inventory system will also be affected by the objectives of the emission inventory, and therefore by implication, factors (a) to (c) above.

The purpose of an emission inventory for the Blackbrook Valley is defined by the aims set out in the IHD project brief in Chapter 1, section 1.3.3. These are reproduced below.

1. To acquire a baseline store of data on existing levels of air pollutants, to be added to the accumulating store of knowledge of the Blackbrook Valley project area.
2. To monitor long term changes in air pollution resulting from development of the Blackbrook Valley, with the aim of monitoring effects on pathways of pollutants in the area, particularly accumulation of pollutants in biological organisms.

3. To assess the implications of the above and to contribute the relevant information to the monitoring processes of future management and planning proposals.

In order to get some idea of how to compile an emission inventory with these aims the relevant literature was consulted for guidance. The objectives of an emission inventory, as described in the literature, indicated a wide variety of possible applications. Ball and Radcliffe[3] identify five areas where an emission inventory can be applied. These are:

1. In urban planning.
2. In the economic assessment of policies which involve control of emissions to improve air quality.
3. In the design of air pollution monitoring networks.
4. In dealing with high pollution episodes.
5. In assessing trends in air quality.

An emission inventory may be used for one or more of the above depending on the goals and resources of the organisation concerned. For example, at the regional level, a governing authority would be concerned with all aspects of air pollution management and planning e.g. public health, housing, traffic control. In order to achieve a coordinated policy this may be formalised into a so-called "Air Quality Management System" (AQMS). The use of an emission inventory will be part of this coordinated approach, which may include other elements such as the development of a monitoring network for measuring ambient air pollution concentrations. The applications in 3 and 4 above are mainly concerned with this type of approach.

Application 2 above is also an objective frequently included in an AQMS. According to Ball:

> "for cost effective policies on air quality to be developed it is essential to establish a connection between the ambient concentrations of pollutants and their sources."(4)

He considers that the first step is to establish an emission inventory.

None of the applications listed in 2 to 4 seemed particularly appropriate for the Blackbrook Valley during the timespan of the present research. These rely on the existence of an established framework of monitoring or data collection (or commitment to one). The usefulness of an emission inventory as a means of obtaining data for the Blackbrook Valley, has been outlined (section 1.4.2). The objectives can be summarised as being firstly, to obtain a general picture of air quality for the area and secondly, to map the distribution of sources in the area and estimate the proportion of emissions contributed by each to the total. The applications listed in 1 and 5 appeared to be the most appropriate general categories for this.

Weber(5) lists a number of more detailed objectives for which an emission inventory might be used including:

(a) The assessment of the current emissions situation in a certain area, such as determining the contribution from the various emitter categories.

(b) The prediction of changes in the emissions situation due to the addition of new air pollution sources.

(c) The prediction of changes in the emissions situation due to certain control strategies.

(d) The prediction of changes in the ambient air quality from the above-mentioned changes in the emissions situation.

Many of these uses would be particularly applicable to the work of Dudley local authority. As outlined in Chapter 1, the Nature Conservancy Council is more interested in pollution effects than in sources of pollutants. However it is indirectly interested in obtaining information on emission sources because this would contribute to future planning for industrial development, for example by assessing acceptable pollutant loads for different areas. The options identified by Weber summarise quite neatly the type of applications for an emission inventory for the Blackbrook Valley. Comparing the above list with the IHD project aims, it can be seen that the assessment of the "current emissions situation" in (a) would form the required baseline store of data for work on pollution sources and hence any future air pollution monitoring, or decision-making, related to the Blackbrook Valley Project. The "prediction of changes in emissions" (b) to (d) in the Blackbrook Valley is an idea very much of interest to both the Nature Conservancy Council and Dudley Council. This would be required particularly for monitoring long-term changes resulting from the development of the Enterprise Zone, which represents a large potential for "new pollution sources". On the basis of information obtained on sources, both new and old, the Nature Conservancy Council in conjunction with the local authority would want to be able to test different strategies, e.g. for controlling emissions or selectively locating industry, and to be able to predict the emissions and changes in ambient air quality which would result from implementing these strategies.

Many of the above uses for an emission inventory would require a dispersion model. This emphasises the need to develop both aspects together.

2.1.3 The collection of data

Assuming an emission inventory was to be compiled for the Blackbrook Valley, with the objectives described, the next stage would be to consider how the required data would be collected.

The World Health Organisation[6] and others have given general guidance on how to set about establishing an emission inventory. One of the first steps is to decide on a system for classifying different sources. The usual method is to divide sources into two categories, point sources and area sources. Point sources are defined as those that emit more than a specified amount of pollutant, the amount being chosen by the organisation making the inventory. Point sources are surveyed individually to establish their emissions, while sources that emit less than the specified amount of pollution are treated together in groups called area sources.

The Greater London Council (GLC) carried out a major survey which provided a model for the above approach.[7] The purpose of the survey was to provide a complete emissions inventory of sulphur dioxide for the Greater London area; the results subsequently formed the basis for studies of fuel use and SO_2 emissions[8] and energy use in London.[9] For the purposes of the above survey the GLC defined a point source as one whose emissions were greater than 30 tonnes of sulphur dioxide *per annum*, or 15Mbtu *per* hour, whichever was appropriate. This category therefore included all major industrial plant and power stations. The remaining sources were treated as area sources. The procedure adopted for calculating emissions from these sources was as follows.

Point sources. First of all a list of potential point sources was drawn up, based on the knowledge and experience of the Environmental Health Officers. A postal questionnaire was then sent to each of the industrial premises on the list. The questionnaire asked for specific information on the type of fuel used and the approximate annual rate of fuel consumption, from which the required emissions were obtained.

Area sources. Firstly, the study area (London) was divided into a number of smaller geographical units. The sources were divided into different category types: domestic, small industrial and commercial/institutional. The number of sources for each category was then determined for each geographical area. Finally the total amounts of fuel used in the study area, less those used by point sources, were apportioned to source categories and then to geographical units.

The above division into, and treatment of, point and area source categories conforms more or less to the system described by Weber.[10] He considers there are 2 methods used to obtain emission data. The first method, which he terms the individual approach, consists of the collection of detailed data on individual emission sources by means of questionnaire and/or interviews. The second method is the estimation of emissions based mainly on statistical information, called the collective approach. According to Weber the collective approach is used more often to investigate a large number of similar emitters, whereas the individual approach is used for individual emitters. Thus it can be seen from the previous discussion that, in general, the individual approach would be used to estimate emissions from point sources. The collective approach is more appropriate to area sources. These two approaches are now discussed.

Individual approach. The use of questionnaires has proved successful in a variety of air pollution studies. There are two main requirements. Firstly, it is necessary to assess what information is required. This is determined by establishing the purpose and objectives of the inventory information, as described in section 3.1.2. Secondly, based on this information, the questionnaire forms must be prepared in such a way that the required information can be obtained. The type of questionnaire can be varied in accordance with the detail of information required. The minimum information requested in any questionnaire would be the geographic location of the facility and all information related to its identification and definition (e.g. plant name, address, responsible person to contact, and materials processed or used). More detailed information may be required. In this event the services of a questionnaire design specialist may be required. Weber also recommends involving a computer specialist in the designing of questionnaires to facilitate the computer entry of data.

Collective approach. It is not always feasible to obtain information on emissions on a source-by-source basis. In this event it is necessary to make estimates of emissions using emission factors, statistical information, and other available data. The main sources of information on industrial production processes and fuel consumption are the relevant government departments responsible for collecting these statistical data; in the case of Dudley Council this is the Department of Environmental Health. Information on population, housing, number of employees, and land use, for example, would be found in the departments concerned with collecting planning and census data (at Dudley Council, Department of Planning). Other data are published by industrial associations, and by central government departments and organisations.

Emission factors are an important source of information, applicable to the individual or collective approach. These are figures which are used to relate the quantity of pollutant emitted by a certain process to some indicator such as production capacity, rate of raw material usage, or quantity of fuel burned. Published standard emission factors e.g. those published by the US Environmental Protection Agency[11] are compiled from source tests, material balance studies, and other estimates for the major causes of air pollution. There are limitations to the applicability of emission factors. Weber comments:

> "In general, emission factors are not precise indicators of emissions from a single source, but are most valid when applied to a large number of sources and causes."[12]

The previous discussion shows that, for many purposes, the terms individual approach and collective approach are synonymous with the treatment of point sources and area sources respectively. Most studies in the literature distinguish point sources and area sources. Therefore both approaches are generally required. There is however another dimension to the whole problem of emission inventory data collection. The World Health Organisation[13] divides emission inventories into two types:

(1) rapid methods that provide reasonable estimates of emissions, and
(2) very elaborate procedures that yield more detailed and precise information.

The rapid method is considered appropriate if there are limitations on time and resources available and when only estimates of the major pollutants are needed. An example of this approach is described in a report by Ozolins and Smith.[14] Using this method the study area is divided into geographical subdivisions according to some convenient system, e.g. grouping similar sources together. The fuel consumption and emissions for the different sources are calculated and apportioned to different categories of user as previously described for area sources in the GLC study.

By contrast, for a detailed source inventory the objective is, wherever possible, to determine actual emissions from specific point sources and area sources in preference to using estimates. According to the WHO report a detailed source investigation requires more time, manpower, and resources than a rapid survey but the data obtained "are sufficiently detailed and accurate for use in development of air quality diffusion models and the manipulation of emission reduction strategies."(15)

2.1.4 Blackbrook Valley inventory: analysis of options

The literature showed that there were three aspects to the compilation of an emission inventory, namely

(1) point sources - area sources

(2) individual - collective approaches

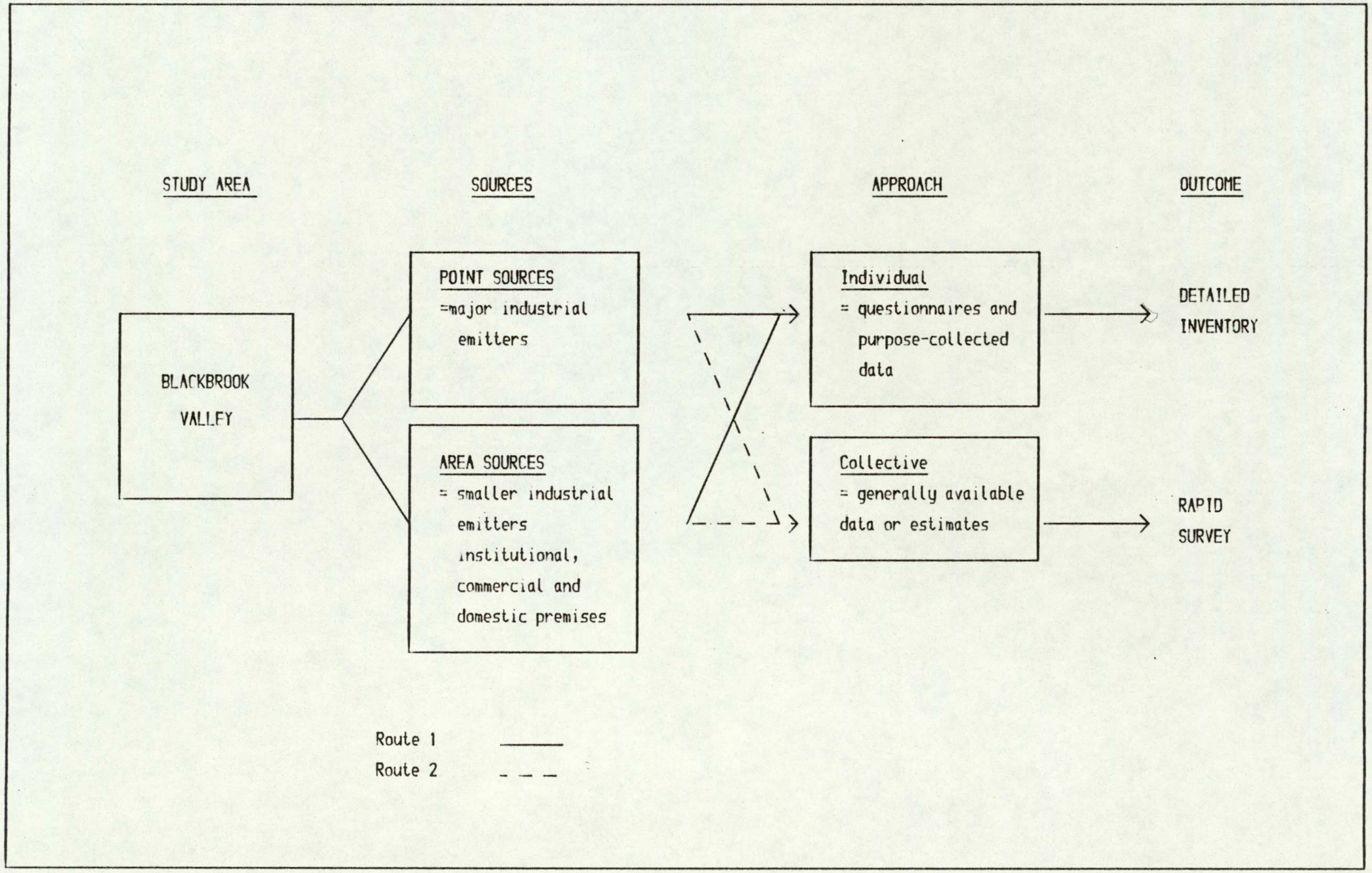
(3) rapid - detailed surveys

The various methods described represented possible approaches for the compilation of an emission inventory for the Blackbrook Valley. The options for compiling an emission inventory are summarised in Fig. 2.1. It was now necessary to assess in more detail which of these was appropriate and how it might be applied. There were two aspects, namely

(i) to decide what source categories were to be considered and in particular how these would be sub-divided, and

(ii) to look at what information could be obtained for the Blackbrook Valley and how this information could be used to compile an emission inventory.

Fig. 2.1 Air pollution emission inventory: summary of options.



(i) Identification of source categories

At the start of the present research study the Blackbrook Valley had only one large pollution emitter, namely Round Oak Steel Works at Brierley Hill. In December 1982 this plant was closed. The remaining industries in the Blackbrook Valley consist mainly of process heating, light engineering plant and a variety of other industries including metal processing. These would be the main point sources in the study area. However for the purposes of constructing an emission inventory it would not be reasonable to consider all of these individually.

A criterion was required for distinguishing between point sources and area sources. Examination of the relevant literature showed that this was generally made on the basis of differences in emission rate. The critical values selected varied between studies. Many of the studies in the literature were carried out for very large areas. These commonly define point sources in the range 50 - 100 tonnes *per annum*. The GLC figure already noted (p.47) was lower but even this was used for a relatively large area where sources included major emitters such as power stations. As the Blackbrook Valley has no emitters of power station scale and the total number of emitters is also small, a different selection criterion for distinguishing point sources was needed. One possibility was to draw up a list of the "top ten" polluters i.e. major industrial premises to be treated in detail as point sources. The remaining sources could then be divided according to some convenient system. This process would have the advantage of being simple, if fairly arbitrary. A second option was to consider using the Land Use Classification codes of different air pollution sources as a basis for allocating to each category. Thus industrial plants would form the principal point sources, and institutions and domestic properties the main area sources.

(ii) Obtaining information

As outlined in Chapter 1 there are two methods of obtaining information on air pollution levels in the Blackbrook Valley, namely (i) by the direct collection of data and (ii) by the use of available information. The same options apply to obtaining information on emission sources.

Data collection. The collection of air pollution emission data by direct measurement was limited. However, as indicated in the World Health Organisation definition on page 42, this would not preclude the possibility of compiling an emission inventory. It is usual for emission inventories to make use of estimated data. Even where direct measurement is possible it is not necessarily practicable for every source, e.g. for reasons of cost. In the case of the Blackbrook Valley this would be the main source of data.

Available information. Dudley Council has a large amount of available information in its records both as part of the day-to-day administration of work (Pollution Division, Planning Department etc.) and in relation to monitoring of the Enterprise Zone. These would provide a major source of data for use in the study.

The availability of information for the estimation of emissions from industrial sources was particularly important. These were likely to be the main emitters and, therefore, the main point sources in the Blackbrook Valley. Dudley Council carries out an annual survey of the Enterprise Zone, including the collection of information on air pollutants. This was considered the most likely source of information for this purpose and an examination of the 1982 Annual Survey data was carried out. However the information was found to be inadequate for the purposes of calculating emissions or defining point sources. It was necessary to consider alternatives. The sources of information considered were (a) questionnaire and (b) fuel suppliers. Full details of these options and the Annual Survey are presented in Appendix B. The following is a summary of the findings.

a) Questionnaire. A purpose-designed questionnaire would have offered the optimum means of obtaining the required information on industrial premises (point sources) in the Blackbrook Valley. The advantages of the technique are:

Firstly, more specific information can be obtained for individual emitters than would be possible by consulting general records.

Secondly, a questionnaire gives more control over the format, timing etc. of the data collection process and can therefore be purpose-designed for the required inventory.

In view of certain conditions related to the Enterprise Zone, requests for statistical information were not felt to be advisable. For this reason a questionnaire approach was not possible in the present study. This is discussed more fully in Appendix B.

b) Fuel Suppliers. The second approach was to contact suppliers of the main types of different fuels: solid fuel, petroleum fuels and gas. This achieved some success. In particular the approaches to the West Midlands Gas Board and to UK Petroleum Industrial Association resulted in useful information of type required in the present research. For both of these sources the data was divided by different categories of user corresponding to those found in emission inventory studies. In the case of gas records this fact together with the ease of access to the information meant that this would provide a useful source of direct information for use in the study. Information on solid fuel-use could not be obtained directly from suppliers. It was concluded that other methods, e.g. use of local authority data, would be required to obtain any useful information.

2.1.5 Summary

According to the literature the usual method of treating point sources is by questionnaire (the individual approach). As previously described, this approach was not possible in the Blackbrook Valley. This suggested that the only possible strategy for the compilation of an emission inventory for the Blackbrook Valley for point and area sources would be to rely on existing or generally available information i.e. the collective approach. Furthermore, unless specific resources could be made available for the compilation of an emission inventory, the establishment of a system for the collection and management of data would have to be incorporated into the normal routine system of government work.

It can be seen from Fig. 2.1 that the only type of inventory possible for the Blackbrook Valley would be a rapid survey.

2.2.0 AIR POLLUTION DISPERSION MODELLING

Dispersion models have found widespread application in studies of urban air pollution in the UK.[16] Typically, however, they deal with areas which are both larger than the Blackbrook Valley, and have more limited requirements in terms of geographical resolution. The following sections (2.2.1 to 2.2.5) examine the requirements of a dispersion model for the Blackbrook Valley, and consider how this might be found.

2.2.1 Requirements of the model

Proper definition of the required model objectives is essential as the first step in determination of a suitable model. According to Holling[17]

> "From the moment we begin to work on the problem, we have to use all our resources and expertise to impose our goals on the solution, instead of allowing the problem to impose on us a solution which is unsatisfactory."

The basic purpose of a model for the Blackbrook Valley, as outlined in the introduction, is to provide a means of relating data on sources of air pollutants and emission sources to air quality distribution. Specifically, the model will be the tool needed to use purpose-obtained inventory data and/or meteorological and other data generally available. In the short term this will enable data to be used to provide a map of existing air quality in the Blackbrook Valley. In the longer term it can be used with either measured or presumed data to enable monitoring and/or prediction of changes in air quality.

From the point of view of the NCC there will be two main uses for information from a dispersion model:

1. To increase the level of knowledge of the study area. In particular this will be to enable the assessment of air pollution effects on biological organisms. (ecological effects monitoring)
2. To contribute to future planning/management of air quality, re. conservation sites. (environmental planning/management)

These uses correspond to the two models in Fig. 1.3 (p.32), making the links between air concentrations and effects, and emissions and air quality respectively. These uses (models) are now considered in detail.

1. Ecological effects monitoring

The main purpose of using information from the model will be in ecological studies to enable data on air pollution concentrations to be related to effects on biological organisms. Information on air quality can be used, for example, to assess the fallout rate of pollutants and hence the contributions made over time to different components of the environment, in particular to the soil surface, to water bodies and to vegetation. This type of information is needed in studies of the ecological effects of air pollution in the Blackbrook Valley, in particular in assessing the accumulation of pollutants in food chains.

In any ecological studies the model will need to take account of different time periods to enable a) seasonal and b) historical analyses to be made.

a) Seasonal analysis. Evaluations of the average annual distribution of pollutant concentrations provide a certain amount of information useful to ecologists, for example enabling year by year comparisons of the same study area or for general comparison of different sites. However, the seasonal fluctuations in pollutant concentrations are more significant in relation to biological effects, particularly when correlated with other environmental conditions/factors, such as nutrient availability, population numbers or growth period. Seasonal analysis of air pollution data, for example by a model, is essential in work aimed at evaluating cause-effect relationships between pollutants and biological organisms.

b) Historical analysis. A model enables an air quality distribution map to be made from data relating to past, present or future conditions. In this way data on pollution concentrations for different periods can be compared with relevant survey data for plant and animal distributions, for example to monitor the effects of changes in planning policies for improvements in air quality.

Alternatively, given the relevant information on biological effects (obtained from ecological studies such as described above) the model can be used to assess the benefits of reduction in pollution levels in the Blackbrook Valley. By testing out different strategies using the model it would be possible to determine how this could be achieved.

2. Environmental planning/management

The basic purpose of the model from the planning point of view is to use available data on meteorological conditions and pollution sources to provide information on the distribution of air pollution over the planning region, in this case the Blackbrook Valley. The detailed type of information required depends on the specific application. For example, in local authority work, information from the model will be useful for monitoring pollution levels: either to check that these meet the standards required by statutory regulations, or to assess the effects of changes in discharge restrictions. Such applications for the model accord with views expressed by Dudley Council (Pollution Division) in relation to the use of the Chimney Height Memorandum.[18] However from the point of view of the NCC the main applications, and hence informational requirements of the model, go further than this kind of use. In particular, the requirements of the model in terms of planning/site management are very closely linked with the kind of decisions with which ecologists will be concerned.

Thus, given a knowledge of ecologically valuable sites or areas of interest (an SSSI for example) and the relationship between pollutant concentrations and effects, the model could be used to grade planning areas according to the degree of pollution "risk" they represent. The result of this process might be a planning distribution map showing the preferred permissible level of future development for different areas around the site of interest.

2.2.2 Types of models: possible approaches

The modelling of air pollution can be approached from two different perspectives, namely

a) source-oriented

b) receptor-oriented[19]

These approaches can be described in terms of the two models in Fig. 1.3. In the first type of approach, the distribution of pollutant from a specific source is calculated from a knowledge of emissions and from data on the various factors affecting dispersion. By a process of summation the distributions for individual sources can be combined to give a picture of the whole modelling region. In the second approach, the receptor-oriented approach, no assumptions are made concerning the emissions and only ambient concentrations are measured for specific receptor sites. Statistical or other methods are applied to the observed data in order to assess the probable origin of pollutant contributions from different sources. The NCC is interested in both these approaches. The reasons for this are related to the different applications of the required model, which will now be discussed.

The source-oriented approach works from known information (i.e. existing or presumed source data) to give a picture of air quality, using an established relationship to link emissions and concentrations. This in general is the approach adopted by administrative organisations, e.g. local authorities, and found in many of the urban pollution studies in the literature.[20,21] The starting point for such models is usually a source or emissions inventory. An important feature of the model adopted by the NCC is that data requirements must be compatible with the type of information used by planners. Using a source-oriented model, data can be updated easily. Changes in information, e.g. data on new sources, can be accomodated. By substituting estimated values for data on existing sources, the model can also be used predictively to assess the effect of future developments.

Within the general framework of monitoring/mapping of air pollution in the Blackbrook Valley, the NCC is concerned with the impact of pollutants on a specific receptor site, namely Saltwells Wood LNR. This could be treated as a special point of interest, in the calculation of pollution spread from different sources, using the method described above. However, in principle the receptor-oriented approach offers a more useful means of modelling Saltwells Wood as a specific target for pollutants. Using the receptor-oriented approach, the calculated contributions from sources or areas around the nature reserve will represent the total (integrated) outcome of all causative dispersion factors (i.e. dose multiplied by exposure). This gives, in other words, direct information on the areas or directions from which the main pollution risk occurs. In conjunction with information on biological effects, data from a receptor-oriented model could be used to determine cause-effect relationships, linking in with the requirements of ecologists as discussed in the previous section.

2.2.3 Practical implementation: Data requirements

Both source-oriented and receptor-oriented models provide important tools for the development of air pollution control strategies. However, in terms of calculation, the two approaches commonly have different mathematical bases and data requirements. These need to be examined in relation to the required model.

The source-oriented approach is essentially a process of mathematical simulation. Each of the stages (equations) in the calculation expresses mathematically the effect of a particular factor on the dispersion of a pollutant. Models based on such cause-effect relationships are described by Benarie(22) as "explanatory" models. Because of the underlying causal relationships between pollutant emissions and concentrations, explanatory models are very adaptable in terms of data requirements. They need not use purpose-collected data if this is not available. This has a number of advantages. Firstly, it means that the models are able to use generally available data. Secondly, they can be used with estimated or presumed data to predict future air pollution concentrations.

According to Benarie: "Receptor-oriented models are generally descriptive and less directed towards establishing cause-and-effect relationships".[23] This is because receptor-oriented models tend to be based on an analytical, rather than a simulation, approach. There is no established equation relating pollution sources and concentrations. Instead any causal associations in the observed ambient concentrations at specific receptor sites are derived purely statistically.

Among the multivariate statistical techniques that have been used as source-receptor models, factor analysis is the most widely employed.[24] The basic aim is to allow the variation in a set of data to determine the number of independent causalities i.e. sources of pollutants. Because of this there is no opportunity to allow for future (projected) changes in emissions in the manner of source-oriented models. The predictive performance of statistically based receptor models is therefore restricted to short term forecasts based on up to date measurements of ambient concentrations. Not all receptor models are statistically based, for example the Chemical Element Balances (CEB) method described by Gordon.[25] In this method the contributions made by different sources are estimated from concentrations at (receptor) sites by relating to known source-strength profiles for different types of sources. However, in common with the various statistical (factor analysis) approaches, the CEB method still relies on the availability of up to date information on concentrations. Furthermore, with all of these methods, the data requires to be of a very high quality and to include all pollutant species present in the air. This can only be achieved using a comprehensive monitoring network for the sites of interest.

Because of the exacting data requirements, receptor models of the type described above are clearly unsuitable for use in the present research. However receptor-oriented models can be derived from source-oriented models. Benarie considers the case of box models. Normally the model uses source/emission data as input to derive a concentration value as output.

> "However if we use a past or present measured concentration as input and investigate changes in source strength in order to find some other concentration (the desired air quality), we arrive at the receptor-oriented symmetrical counterpart of the box model, which is called the rollback model or proportional scaling model."(26)

The same approach can be applied to any suitable source-oriented model. In terms of data requirements the resulting receptor-oriented model will be the same as the source-oriented models from which they are derived.

Source-oriented models form the basis of most of the modelling equations and experience described in the literature. In terms of calculation and data requirements, they offer a number of features which match with the proposed uses of the type of model required for the Blackbrook Valley. The receptor-oriented approach is of interest to the NCC, although many of the statistically based models would be unsuitable. In summary, the use of source-oriented models "backwards" would offer the best solution to the need for a receptor-oriented approach.

2.3.0 CHAPTER SUMMARY

This chapter has examined the use of the emission inventory and dispersion modelling approaches in the Blackbrook Valley. It is clear that these approaches share a number of similarities in terms of data requirements, and applications and should be treated as complementary aspects of an air pollution management programme.

Emission inventories are commonly used in air pollution studies as a means of obtaining detailed information for emissions and sources and, in fact, provide the basis for many of the modelling studies in the literature. The importance of clearly identifying the purpose of the information from an inventory was highlighted.

From examination of the literature, a number of different approaches for obtaining emission inventory data were identified. These were:

point source/area source approach
individual/collective approach
rapid/detailed survey approach

These were examined in the context of the Blackbrook Valley. It was judged that industrial plants, which in the Blackbrook Valley are concentrated in the Enterprise Zone, would be the main point sources, while domestic and institutional establishments would be considered as area sources. Direct requests for information on industrial sources (the individual approach), e.g. by means of a questionnaire, was not possible in the present study, though some useful information on fuel-use was obtained by direct enquiry. It was concluded that, in general, the compilation of emission inventory would rely on the use of generally available data (collective approach).

The literature indicated that for dispersion modelling a detailed survey of emissions and sources would be required. Existing data on point sources was not detailed or reliable enough to be used in a detailed survey. It is therefore suggested that the only remaining option would be to undertake a rapid survey using generally available information/collective approach.

The NCC needs a dispersion model to monitor and predict air pollution concentrations in the Blackbrook Valley. This information will enable ecologists to a) anticipate effects of air pollution on biological populations/habitats, and b) make suitable recommendations to planners for future management of special sites such as nature reserves e.g. to restrict pollution levels.

In addition, an air pollution dispersion model offers the means to organise and consolidate large amounts of research information/data for repeated access by any number of users. From a national standpoint this would give the NCC the basis for making reasoned judgements in pollution-related matters and so enable a consistent and objective approach in any recommendations offered.

The benefit of model in the decision-making processes described is that it allows testing of different conditions and of multiple (alternative) scenarios which it is not possible to experience in reality either because of the time scale involved or because of the impracticablity of obtaining measurements. The ability to test alternative scenarios has parallels with environmental impact assessments. In air pollution management, as in other fields, planning decisions involve assessment of all possible effects, beneficial and non-beneficial, social, economic and environmental. When considering the siting of new industries it would be important to be able to compare the above effects for different sites or a range of different planning proposals before a decision was made. To be able to make such decisions a model is required.

The use of modelling is fairly complex. The value of the results obtained from modelling would depend on the quality of input data used. In the Blackbrook Valley the availability of information for the compilation of a detailed emission inventory appears to be inadequate. Appropriate meteorological data could also not be found or collected.

Many of the models described in the literature were too large-scale and/or too complex for use in the present research. Developing a suitable model would be time-consuming and costly and was therefore deferred until a precise specification of a required model could be drawn up. As the focus of the research later changed it was decided that the emission inventory and dispersion modelling approaches would not be pursued further.

CHAPTER 3

DEVELOPMENT OF RESEARCH OBJECTIVES (Part 2)

CONTENTS:

3.0.0 OUTLINE

This chapter examines the use of biological indicators as an inexpensive means of collecting data on air concentrations in the Blackbrook Valley. It begins by setting out the theoretical basis for the use of biological species as indicators of air pollution, and describes different plant-indicator responses which can be used. The applications of indicators and monitors are then examined in the context of the requirements of the present research. Lichens were found to be the most suitable indicators for this purpose. The chapter concludes with an assessment of the methods available.

3.1.0 THE USE OF BIOLOGICAL INDICATORS

3.1.1 Theoretical background

The effects of air pollutants on biological organisms, particularly on plants, have been widely reported. The observation of these effects, for the purposes of detecting or measuring air pollutants, has in recent years become a valuable tool in air pollution surveys. The terms "biological indication" or "bioindication" are used in this context, for example by Manning and Feder.[1]

The basis for the use of biological species as indicators is that their form, performance or behaviour can be related causally, directly or indirectly, to environmental conditions. Zonneveld calls these relationships "correlative complexes".[2]

F.E. Clements is credited as one of the first writers to describe the use of plants as indicators. He wrote:

> "Every plant is a measure of the conditions under which it grows. To this extent it is an index of soil and climate, and consequently of the behaviour of other plants and animals in the same spot." [3]

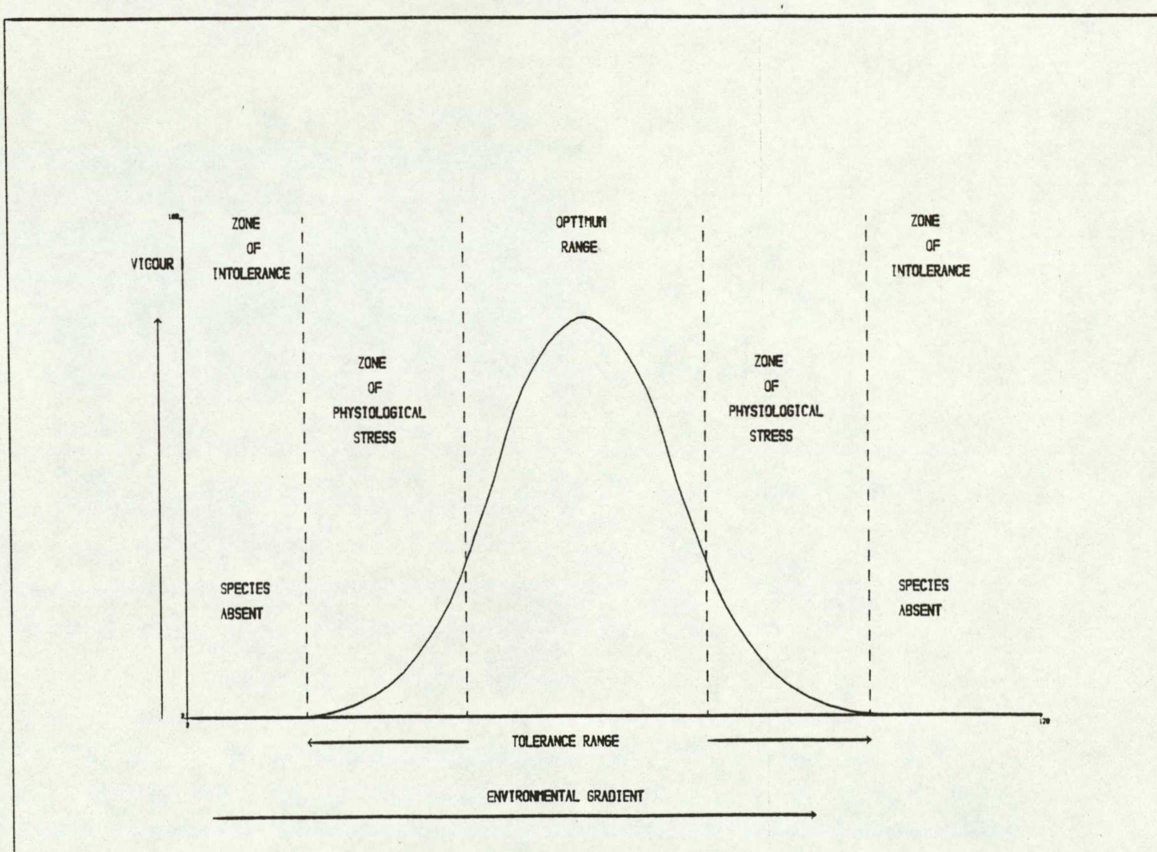
By means of laboratory-based ecological studies, the specific requirements of any particular species, a plant for example, can be established in terms of environmental gradients such as pH, nutrients, water availability. For each of these environmental factors there is typically a range of values for which growth is optimal, shown in Fig. 3.1. Outside this range the organism will be physiologically stressed to a greater or lesser degree and may develop visible stress symptoms. The minimum and maximum levels at which the plant is unable to tolerate further stress will mark the theoretical limits of its distribution for that factor and influence its presence or absence in a particular location. Ecological studies for example by Grime and Hodgson[4] show that, in practice, the physiological (potential) niche of a plant differs from the ecological (actual) niche realised in field conditions. The ability of a species to occupy its potential optimal environmental range is modified by various factors, which according to Zonneveld, limit the use of bioindication.[5] In particular these include:

a) The complexity of environmental factors. Species do not respond to environmental factors separately, but to the combined influence of all factors. These may interact to produce effects greater than the sum of the individual factors (synergism).

b) Interaction with other biological organisms. This includes the effects of competition with and/or tolerance of other species.

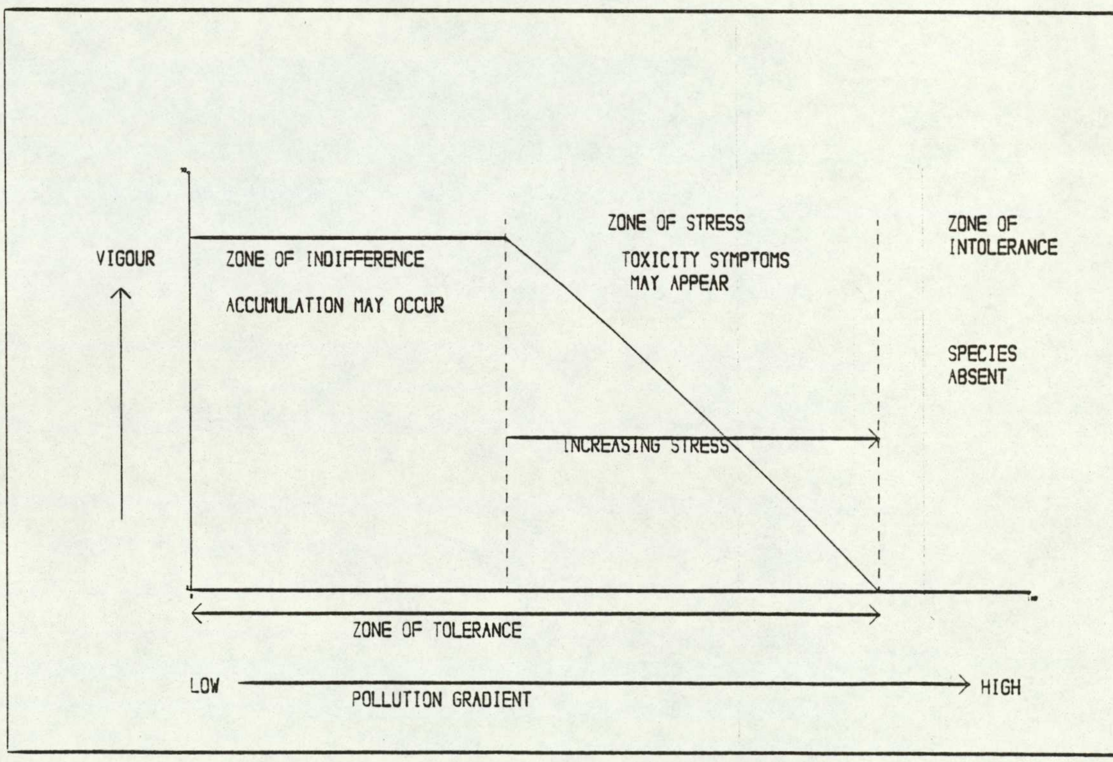
The model shown in Fig. 3.1, is for an environmental factor which is needed by the plant and is characterised by a minimum and maximum requirement for the environmental factor concerned. This gives rise to two zones of intolerance. Below minimum required levels of the environmental factor will typically result in deficiency symptoms in the plant, whereas excess levels will result in toxicity. This model is applicable to many environmental factors including major plant nutrients e.g. nitrogen, potassium, phosphorus and also trace elements such as copper, iron, magnesium. When present in toxic amounts in the environment these may be considered as pollutants. However, for many environmental pollutants there is no physiological requirement by the plant and only an upper zone of stress symptoms. The model for this type of interaction would therefore appear as in Fig. 3.2.

Fig. 3.1 The relationship between performance or vigour of a typical plant and an environmental gradient.



Source: Martin and Coughtrey[6], page 24.

Fig. 3.2 Relationship between performance or vigour of a typical plant and a pollution gradient.



Source: Martin and Coughtrey(6), page 24.

3.1.2 Types of bioindicator

There are essentially two types of bioindicator: those that can be used to provide qualitative evidence of the presence of air pollution (*indicators*), and those that enable quantitative measurement of air pollution effects (*monitors*). The terms (indicators and monitors) have been reviewed by Martin and Coughtrey.[6] These authors consider that implicit in the term "indicator" is the ability of an organism to simply indicate the presence or absence of any particular factor, in this case air pollution. In monitors this ability results in biological effects which can be linked quantitatively to conditions in the environment. According to Manning and Feder:

> "A (plant) monitor must be an indicator, but it must also help answer the question: How much?"[7]

The specific characteristics which enable plants to be used as indicators or monitors vary with the species selected and which part of the previously described models (Fig. 3.1 and Fig. 3.2) is being exploited. There are a number of different types.

Where a species is especially sensitive or resistant to air pollution, presence-absence of that species can be a useful indicator. Other species reveal the presence of air pollution by so-called "typical" stress symptoms, i.e. characteristic changes in appearance, for example colour. These are described in detail in various texts[8,9,10], and illustrated in a number of pictorial atlases.[11,12] The changes involved may be specific for air pollution or a particular pollutant (e.g. ozone damage on Bel W3 tobacco plants), or non-specific (e.g. general chlorosis or reduction in vigour). The latter are often similar to symptoms produced by other agents such as frost, disease or nutrient deficiency. The usefulness of the organism for bioindication will obviously be much greater with increased specificity of the response. A number of German authors include the idea of specificity in their terminology. Thus Knabe comments:

> "A bioindicator reveals the presence of air pollutants by showing typical symptoms which can be distinguished from the effects of other natural or anthropogenic stress."[13]

A distinction is sometimes drawn between sensitive bioindicators and accumulative bioindicators.[14] The first respond in a sensitive way to pollutants and the latter accumulate these substances for a short time without perceptible symptoms of injury. In the latter event it may be possible to analyse the accumulated substances and relate these to concentrations of air pollution. Terms such as "accumulator"[15] or "bioaccumulator"[16] have been variously applied to these.

The literature on bioindication is inconsistent. It is clear that a number of the above terms are used differently by different authors. Few authors make a specific distinction between indicators and monitors. Instead the term "bioindicator" is variously defined or sub-divided according to the particular characteristics used for evaluating the air pollution effects. According to Grodzinski and Yorks[17] there are three basic categories of use for bioindicators suggested in the literature, namely

- True indicators, in which the degree of pollutant-incited damage is related to morphological and/or physiological symptoms in one selected species.
- Scales of indicator species, relating the level of air pollution to the presence or absence of sensitive species.
- Accumulators or collectors, being plant or animal species acting as a quantitative collector and/or accumulator of air pollutants.

For the purposes of considering the broad requirements of a survey the simple distinction of Martin and Coughtrey is preferable to many of the more detailed definitions. The precise nature of the bioindication response and its specificity are characteristics of the different species and can be chosen according to the detailed requirements of the survey. The question of which bioindicator response is appropriate in the context of the Blackbrook Valley will be discussed later. Initially it is important to know whether or not a quantitative or qualitative measure is required. The applications of indicators and monitors are quite different and these are now discussed.

3.2.0 PRACTICAL APPLICATION

3.2.1 Indicators or monitors?

The reason for undertaking a biological survey in the Blackbrook Valley is to attempt to measure (and ultimately map) differences in concentrations of air pollutants, in other words to obtain quantitative rather than qualitative information. In general, biological organisms which are purely indicators will be unsuitable for the above purpose, because they give only a summary or overall representation of environmental conditions. It is difficult to establish cause and effect from this type of data. Many environmental factors contribute to the distribution and vigour of any particular species. Hence information from individual indicator species, particularly presence-absence data, can be difficult to interpret. As one author comments:

> "The absence of certain species alone cannot be used as indicator for air pollution as it may also be the result of other causes."(18)

There are three possible solutions to this problem. The first option is to maximise the specificity of the survey by careful choice of indicator species. Recommended indicators for specific purposes are listed in the literature.[19,20,21] The combined use of several different species, for example by means of some kind of species diversity index or multiple presence-absence data, also increases the chances that a correct assessment can be made. However such methods rely on expert knowledge of the locality and the relevant species. In practical terms the employment of these methods by an organisation like the Nature Conservancy Council or a local authority may be no less sophisticated than conventional measuring techniques.

The second option is to use indicator species only where a fairly crude assessment is necessary. This idea is reflected in the following comment of Martin and Coughtrey:

> "To a large extent, biological indicating should be applied with two views in mind. First, for the possible determination or surveillance of gross contamination in the environment (whether natural in origin or the result of industrial operations) and, secondly, for the determination of gross ecological effects."[22]

Unfortunately, the assessment of gross effects is not very useful for studies of small-scale areas, such as the Blackbrook Valley, where the aim is to determine the within-area differences in effects.

The third option is to use monitors. According to Martin and Coughtrey there are two criteria which enable monitoring agents to be distinguished from mere indicators. These are:

a) the provision for regular surveillance, and

b) quantification of how much pollutant is present.[23]

Thus biological monitors enable differences in amounts of air pollutants to be measured in both space and time. These are the requirements of a bioindicator for the Blackbrook Valley.

3.2.2 The case for biological monitors

A number of the above-mentioned authors have attempted to assess the strengths and weaknesses of biological monitors.[24,25,26] From the arguments presented, it can be concluded that there are two basic approaches to their use: non-biological and biological. The first type of approach is to use the test organism essentially as a data-gathering device in place of, or in addition to, conventional (chemical/physical) monitors. The biological response itself is of secondary interest. In contrast, the object of the second approach is specifically to measure the biological effect of the air pollutant(s). The test plant may be either the species of interest or a surrogate for it. The applications of these approaches are now discussed in greater detail.

"Non-biological" approach

Biological monitors cannot reproduce the results that would be obtained by physical or chemical techniques. The main justification for the use of biological monitors in a non-biological role is, therefore, that there are reasons why conventional techniques cannot be used. One such reason is cost.[27] Physical and chemical methods, particularly when used in a comprehensive monitoring network, give a very detailed picture of pollutant atmospheric conditions. The measurements obtained can be very precise in time and space and could not easily be obtained by biological monitors. However the capital cost of setting up such programmes is very high. The techniques involved can also be difficult. Thus according to Muskett:

"The complex nature of most monitoring techniques and the associated analytical procedures unfortunately rule out any effective monitoring programme by many local authorities."(28)

Biological monitors can be much simpler to handle and may not require elaborate setting up/operating procedures e.g. calibration.

In air pollution surveys it is not always necessary to undertake exact or detailed measurements to obtain a useful result. It may be sufficient to identify the location or direction of pollutant sources (a valid objective in itself) and to indicate or justify the need for more detailed investigation work or where best to place conventional monitors. Regarding the use of the mossbag technique for measuring heavy metals Muskett concluded:

"This technique has been proved to be a highly effective rapid survey method which enables hot-spots (sites of abnormally high metal fall-out) to be easily located. These can then be investigated in greater detail and measurements of air concentration, dust and soil levels can be made with more sophisticated equipment."(29)

This approach has the further benefit that, where resources are limited, they can be directed to the most appropriate areas.

Biological methods can be a relatively cheap unsophisticated means of obtaining large amounts of survey data. As in the above case, using mossbags, the results can be obtained relatively quickly.

"Biological" approach

The principal strength of biological monitors is their close simulation of the biological system[30] and hence their ability to enable detection of relevant emissions or the impact of emissions on living systems.[31] Because the effect measured is biological, biomonitors have a number of advantages which conventional monitors do not.

Firstly, they are integrating monitors. Conventional monitors measure selected components of the atmosphere, for particular times during the monitoring period. In contrast, biological monitors react to all the prevailing conditions for the whole of the monitoring period to provide an integrated picture of events. The observation period can be artificially selected using translocated material (discussed in detail later on).

Secondly, biological monitors identify, by means of visible or other measurable effects, the relevant components of the environment which may be damaging. Physical and chemical methods do not necessarily measure pollutants which are harmful to biological organisms. Depending on the technique used, physical and chemical methods may give a relatively good or poorly representative measure. Interference effects are well known with certain methods of sulphur dioxide (SO_2) determination.[32] The hydrogen peroxide (H_2O_2) method, for example,. determines SO_2 by measuring the acidity of the ambient air. It does not discriminate between SO_2 and other acidic or alkaline compounds, for example carbon dioxide (CO_2) or ammonia (NH_3), and so gives a false reading when these are present. Similarly, chemical analysis involving extraction of plant materials in solvent e.g. for detection of metals, may under-estimate or over-estimate the amounts available to the living plant tissues, and so may have little relevance to biological assessments.

The third advantage of biological monitors is that they give a direct quantitative assessment of the degree of air pollution effects in living material. With conventional monitors, the measurements have to be interpreted and/or calibrated in terms of biological effects.

3.2.3 Choice of bioindicator

Biological organisms respond in different ways to varying concentrations of pollutants. According to Seaward:

> "the reaction of organisms to various concentrations of pollutants will vary from species to species, and from individual to individual. Furthermore, these reactions occur at three different levels of organisation:
> (1) physical and/or chemical effect(s) at subcellular level, which may be detected by microscopical analysis
> (2) visible, macroscopical effect(s)
> (3) accumulation of air pollutants without injury"[33]

All these levels can be used for bioindication. A more detailed table of these possibilities is presented in Table 3.1.

Table 3.1 Bioindication: summary of possible research methods.

organisational level	bioindication method
subcellular	biochemical, biophysical electron-microscopical
cellular	cell physiological microscopical
tissue, organs	biochemical, physiological microscopical
organisms (individuals)	ecophysiological, symptomatological chorological
populations, associations	phytosociological
biocoenoses, ecosystems	integrated multi-disciplinary ecosystem research

Source: adapted from Steubing[34]

In general only a few of these options are convenient. Thus:

> "the integration levels most frequently used for indication are tissues and organs, organisms (plant and animal taxa) and communities (vz. vegetation types)."[35]

Similarly, as already described, there are various different ways species can be used to demonstrate air pollutants. Thus in selecting a suitable bioindicator/monitor for a particular survey there are three types of characteristics to be considered:

1. Pollutant/indicator response.
2. Organisational level.
3. Biological species or species group.

The specific characteristics appropriate are dependent on the detailed information requirements of the survey. They are also dependent on other practical considerations. In the Blackbrook Valley the following factors were considered to be important:

a) level of expertise required

b) availability of facilities

c) expense

d) duration of research

To be useful to the Nature Conservancy Council a biological monitoring technique needed to be as simple as possible. This was necessary both

a) to allow the technique to be easily and quickly developed/tested during the research time available, and

b) if a suitable technique were found to enable it to be easily applied by others.

In consequence of the above, methods requiring detailed knowledge of taxonomy or physiological techniques were not appropriate. Similarly, for reasons of cost and time, techniques requiring elaborate laboratory facilities could not be considered. In summary, the requirement was for a survey method which could be applied by non-experts, at low cost and which would produce a relatively quick result. After consideration of these factors, it was judged that lower plants (specifically lichens) would be the most suitable organisms for this purpose. The following reasons support this:

Firstly, lichens (and to some extent mosses) are more sensitive to air pollutants (in general) than higher plants.[36] Sulphur dioxide is considered to be the most widespread and most harmful air pollutant in urban and industrial environments[37] and is one of the primary air pollutants of interest in the Blackbrook Valley. Studies, for example by Richardson and Puckett[38], have shown that epiphytes and especially lichens are far more sensitive to sulphur dioxide (SO_2) than vascular plants. According to the above authors, the sensitivity of lichens to sulphur dioxide

> "seems to be due to the efficient absorption system of lichens and the fact that they absorb over their entire surfaces whereas higher plants are affected by both cuticle and stomata. Therefore in lichens sulphur dioxide quickly reaches toxic levels during a fumigation, especially if the thallus is fully water-saturated, and damage or death of the plant quickly follows if the level of the pollutant is high." [39]

The transfer of absorbed chemicals to different parts of the lichen is very rapid, as shown by Smith.[40] According to Rose, this ability is:

"perhaps an adaptation to the fact that lichens spend most of their time dry, and hence inactive and need, to be successful, to be able to translocate materials very quickly when they become actively metabolic. This means that toxins will be more rapidly diffused than in some other plants."[41]

The second reason supporting the use of lower plants in the present research is that they are more convenient to collect/handle than vascular plants. The lack of a growing medium (soil) in epiphytes also reduces the number of environmental factors which need to be considered.

Among the lower plant groups, mosses and lichens, have been widely used in air pollution studies. The use of mosses has been reviewed by Crump[42]. In particular they have been used in the detection of metals. Goodman[43] developed the use of mossbags as a technique for measuring the fallout of metals in the Swansea/Neath/Port Talbot conurbation, in South Wales. The use of mossbags was considered for the present research. Dudley council had carried out a mossbag survey of the Dudley Borough in the late 1970's. The IHD supervisory team felt that a second survey would give useful additional data, which would provide a historical comparison of data on metal levels (particularly in relation to Round Oak Steel Works). A second survey was carried out by Dudley Council in conjunction with Aston University in September 1982. Details of both mossbag surveys and the data obtained are included in Appendix C.

3.3.0 THE USE OF LICHENS

Lichens have been widely used for studying air pollution effects. These are reviewed by, among others, Hawksworth (44), and Leblanc & Rao.(45) As shown in Table 3.1 there are many possible approaches for studying air pollution effects. The methods for studying these effects in lichens have been mainly of two types: phytosociological and ecophysiological.(46) Broadly speaking the phytosociological approach looks at the ecology of the vegetation in its natural environment (i.e. passively). In contrast, the ecophysiological approach can be considered as an active approach, which looks at the vegetation under experimental, and therefore non-natural, conditions. Many studies use the phytosociological approach and ecophysiological approach in combination. The two approaches are now discussed in the context of the Blackbrook Valley.

3.3.1 Phytosociological approach.

Phytosociological techniques generally consist of some form of vegetation mapping.

In principle, the simplest type of vegetation mapping consists of recording presence or absence of species in the area of interest. A more sophisticated approach takes into consideration the numbers (abundance), percentage cover and frequency of individual species as well. However, as far as the Blackbrook Valley is concerned, there are two main drawbacks with these types of studies. Firstly they are time-consuming. Secondly, specialist knowledge of the relevant species is required both to carry out the survey work and for adequate interpretation of the resulting data. According to Hawksworth:

"If a map based on the lichen vegetation is to be used by non-specialists as a guide to air pollution levels in an area it must be as simple as is consistent with accuracy."[47]

There are better ways to obtain simple information. However, it is through the above types of air pollution studies that the tolerance of different species has been established, and those suitable for use as indicators identified. In the early part of this century Sernander used the distribution of lichen flora to form a general classification of pollution zones in Stockholm.[48,49] He recognised three areas: a central area with no lichens ("lichen desert"), a transition or "struggle zone" where limited numbers of species could be found and, finally, the area of natural lichen distribution. Since Sernander many investigators have devised alternative "zone systems". Four or five zone systems are typical.[50,51] Hawksworth and Rose employed a system based on 11 distinguishable zones.[52]

The zone approach has two advantages. Firstly, it uses easily recognised species with an established pattern of appearance in relation to air pollution levels. Secondly, limited numbers of species are used, so the survey work can be carried out relatively easily and quickly by non-specialists. Using this approach, for example, a comprehensive map of sulphur dioxide pollution in England and Wales was produced from data collected by school children.[53]

The "Index of Atmospheric Purity" (IAP) was another system, first proposed by DeSloover[54], which enabled a numerical assessment of air pollution levels to be made based on the number, frequency and tolerance of lichen species present. Modified versions have been applied by other workers.[55,56] Like zone mapping, this approach requires fairly specialist knowledge of the locality and for the identification of species. Numerical methods in general have also been criticised as being very time-consuming and in not appearing to produce more accurate maps than zone scales.[57]

In the literature both zone maps and numerical methods have been described mainly for mapping large areas, or areas with well-defined gradients of pollution levels e.g. transect studies[58] or studies in the vicinity of industrial installations.[59] The use of uniform substrates for examination of indicator species has also been recommended to reduce the numbers of different species involved in surveys[60], or to enable realistic comparison of sites in different areas.[61] With reference to these points, the Blackbrook Valley is not located near any major pollution sources likely to give a well defined pollution gradient. It also contains insufficient numbers of comparable sites, or substrates, to make an ecological map of local vegetation meaningful.

None of the above phytosociological methods was considered to be suitable for use in the Blackbrook Valley. In addition to the specific drawbacks described, there were a number of problems with phytosociological techniques in general. Firstly, the aim of the present research was to use biological materials as a means of measuring air pollutant levels, not the vegetation itself. Secondly, phytosociological techniques, in general, rely on the use of scales of indicator species. It has already been shown that monitors were required.

3.3.2 Ecophysiological approach

Basically ecophysiological methods fall into two categories

(1) laboratory investigations

(2) transplant studies

(1) Laboratory investigations

The aim of these is to establish a link between ambient pollution concentrations and some measurable physiological response for example vigour, fertility, accumulation of pollutant (e.g. metals, sulphur). This link can be established in detail (calibration) or in relative terms.

Detailed approach. By exposing the chosen indicator to controlled amounts of pollutant, a detailed calibration scale for dose-response can be determined. This can then be used to assess samples of the same material collected from the study area. Disadvantages with this approach, as far as the Blackbrook Valley is concerned, are as follows:

Firstly, for all but the simplest of assessments, laboratory investigations generally rely on large amounts of sophisticated equipment and hence are expensive. The principal aim of using biological materials in this research was as an inexpensive alternative to conventional monitors.

Secondly, the dose-response calibration scales for the physiological response and the specific pollutant (or pollutant mix) concerned need to be developed for the area of interest. This lengthens the time before any data can be gathered. At the end of the survey there may still be limited knowledge of how well the laboratory conditions can simulate the atmosphere being measured in the field.[62]

Thirdly, this type of investigation depends on the availability of suitable vegetation/species (and in sufficient quantities) from the area concerned both for the experimental (calibration) purposes and for the observation of effects.

The above factors would increase the time, expense and requirement for facilities outlined in the list on page 82.

Relative approach. Some biological organisms, notably lichens and mosses can accumulate substances from the atmosphere in a quantitative manner. Samples of such organisms can be chemically analysed, without elaborate calibration procedures, to give a relative scale of ambient pollutant concentrations. This type of laboratory investigation overcomes many of the above problems. However this approach still requires access to a laboratory and may be expensive.

(2) Transplant studies

Transplant studies involve the transfer of plant material from clean-air sites to polluted areas. The material can either be of natural origin or purposely grown under controlled conditions. The main benefit of the transplant technique compared with other methods, is improved control of the biological material. This has a number of advantages.

First of all, the test species does not need to occur in the study area and can therefore be selected according to the particular requirements of the survey. In a small area with a large amount of spatial heterogeneity, such as the Blackbrook Valley, there may be no suitable indicators available unless transplants are used.

The second advantage of transplanted material relates to the question of standardisation. Natural vegetation monitored *in situ* gives a picture of events in which the background history of environmental conditions is unknown. With transplants the origin of material can be checked, or (if purpose-grown) can be controlled. The third advantage of transplants is that the exposure period can be as long or short as required.

Transplant techniques have been adversely criticised. The main criticisms concern the effect of disturbance of the transplant material and the extent to which transplants adapt to new conditions. Farrar comments that the close adaptation of lichens to their environment, particularly with respect to water, makes the interpretation of transplants very difficult.

> "In comparing lichens (even of the same species) from two different habitats under identical conditions, one is in effect treating them differently, as they are being exposed to conditions which deviate from their normal environmental conditions to different extents. Comparison between them is thus complex, except in the broadest of terms." (63)

Some workers, notably Rydza , have claimed that the alteration of moisture could be the real factor affecting transplants in polluted environments.(64) However, the arguments supporting the so-called "drought hypothesis" of Rydza cannot be substantiated by field and laboratory methods.(65) In relation to transplants this idea is also countered by the fact that the controls in unpolluted areas remain healthy and sometimes even show increased growth.(66)

Other researchers have described the difficulties of working with transplants. According to Schönbeck:

> "Such investigations involve the difficulty of maintaining the same ecological conditions which prevail at the original point of growth."(67)

He examined this problem and showed that the lichen's natural ecological conditions could be disregarded at its point of transplantation for an observation period of at least 6 months.[68]

A second criticism of transplants is the validity of control transplants. Because of the (unknown) effect of disturbance on transplants, discussed above, Farrar considers that "it is impossible to do a satisfactory control transplant; the reciprocal transplant is hardly a control."[69] The reciprocal control, in which lichen discs from a clean-air site and a polluted site are interchanged, was for example by Brodo in his experiments on Long Island.[70] However, in this study in 1961, a number of other controls were used, some discs being moved only a short distance from their original position and another being replaced in its own hole. The latter types of control discs would appear to be more adequate tests for any adverse effects of the method on transplants.

A further criticism of transplants, found in the literature, relates to the question of geographical scale. Hawksworth considers transplant studies are "too time-consuming to employ for practical assessments of air pollution levels over large areas."[71] In the Blackbrook Valley study area this should be no problem.

3.4.0 CHAPTER SUMMARY

This chapter has considered the use of biological indicators as a means of measuring air pollution concentrations in the Blackbrook Valley.

Firstly, the literature was consulted to establish the theoretical basis for the use of biological indicators and to examine ways in which they can be used. Two main types of bioindicator were identified: those that provide qualitative information on the presence of air pollutants (indicators) and those that can be used to obtain a quantitative measure of concentrations (monitors). The aims of the Nature Conservancy Council are to establish baseline data on the levels of air pollutants in the Blackbrook Valley study area, and to use this data to monitor long term changes in pollution levels. These aims would clearly only be met by obtaining quantitative data from, i.e. from monitors.

The reasons for using biological monitors were discussed. The literature distinguishes two approaches. The main strength of biological monitors is that they provide a direct measure of effects on biological materials/organisms. Conventional physical and chemical techniques may not measure the relevant pollutants and also require calibration in relation to biological effects to make the data meaningful. The "biological" approach to the employment of monitors makes full use of the biological nature of the test material. The alternative use of biological monitors is a "non-biological" approach, in which the material is effectively used as a collecting or measuring device in place of (or in addition to) conventional physical or chemical techniques. This is the approach proposed for the present research. The reasons for this are that the use of conventional monitors was (a) too expensive, and (b) there were practical difficulties associated with monitoring the study area in detail by such methods.

There are many different ways that indicators and monitors can be selected for a particular situation. The following are variables which require to be considered:

type of pollutant/indicator response required

organisational level

biological species or species group

In the Blackbrook Valley there were also a number of practical considerations.

1. To be an effective replacement for conventional monitors, which were too expensive, any biological method would need to be unsophisticated and inexpensive.
2. The usefulness of the technique adopted would also depend on the ease with which it could be (a) developed in the research time available and (b) applied by other researchers without specialist knowledge.

These factors formed the basis for examination of biological monitoring options. It was decided that lower plants would be more suitable than higher or vascular plants. Firstly they are known to be more sensitive to air pollutants in general (and to sulphur dioxide in particular) than higher plants. Secondly, because of their simpler ecological requirements, they are easier to study.

The lower plant groups considered for this research were mosses and lichens. Mosses have been used mainly as accumulators of metals. This application was of some interest in the present research, to supplement existing mossbag data for the area. A mossbag survey was carried out, in the early part of the IHD project, by Dudley Council. The main air pollutant of concern in the study area was likely to be sulphur dioxide. Lichens were proposed as the most suitable lower plant for bioindication of this pollutant.

Examination of techniques which have been used in lichen work identified two main approaches: phytosociological and ecophysiological. In general, phytosociological studies were based on vegetation mapping. The lack of lichen flora in the Blackbrook Valley area and compexity of many of the mapping techniques made this approach inappropriate. Many of the experimental or ecophysiological approaches used sophisticated facilities, which were not available. The use of natural vegetation would be limited, because of the small size of the area and variability which would make it difficult to locate sufficient biological material of same quality. Transplants were the only option. As the biological monitors would be used as "non-biological" approach, it would not matter that the material originated from outside the study area.

MAIN RESEARCH

THE USE OF LICHEN BOARDS AS A MEANS OF INDICATING POSSIBLE AIR POLLUTION GRADIENTS IN THE BLACKBROOK VALLEY

CHAPTER 4

LICHEN BOARD SURVEY 1983/84

CONTENTS:

4.0.0 OUTLINE

The research presented in this thesis focusses on an examination of the use of lichen boards as a biological monitor in the Blackbrook Valley. This chapter provides an account of the first lichen board survey which was undertaken in the winter of 1983/4. The survey method and results are assessed. Improvements to the method, providing recommendations for implementing a second survey, are also presented.

4.1.0 INTRODUCTION

4.1.1 Background

The sensitivity of lichens to the effects of air pollution was recognised over a hundred years ago. Nylander[1] is generally credited with the first published account (in 1866) relating the decline of urban lichens to air pollution, based on his observations of the cryptogamic vegetation in the Luxembourg Gardens of Paris. Later, as described on page 86, Sernander used the distribution of lichen flora to form a general classification of pollution zones in the city of Stockholm.[2,3] The technique of mapping pollution zones based on field observations of distribution and abundance or diversity of lichen species was used and extended by various workers.[4,5,6]

In general these early studies made use of lichens in their "natural" habitat, i.e. as passive indicator species, although Arnold is claimed to have carried out transplant studies using lichen-covered twigs at the end of the last century.[7] However, this "active" or experimental approach was largely ignored until relatively recently when Brodo[8] developed a technique for removing and transplanting discs of lichen with the underlying substrate. Using a purpose-designed cutting device, he removed lichen discs from trees in a rural site on Long Island, and transplanted them to suitable trees in polluted sites and in control sites. By photographing the transplants at intervals with colour film he was able to record the progress of pollution damage in individual discs, and showed that the death of lichens was correlated with distance from New York.

Standardisation of ecological conditions is important in transplant studies, to eliminate variation due to causes other than air pollution.[9] Brodo selected material of similar age and position (e.g. height, aspect) on trees of similar species or with similar ecological requirements. However, in many polluted areas trees offering comparable ecological conditions may be hard to find. In his study of the industrial Ruhr area, Schönbeck[10] adapted the technique of Brodo to allow transplantation of lichens without the need for trees. He created standard exposure conditions by fixing lichen bark-discs into holes drilled in wooden boards mounted on steel posts.

4.1.2 Pilot survey

The Nature Conservancy Council (NCC) needed a relatively cheap means of obtaining a measure of air pollution levels in the Blackbrook Valley. As outlined above, the lichen board method developed by Schonbeck had certain features which offered a possible way of obtaining such data. A pilot survey was carried out to test the suitability of this method. The survey had the following objectives:

1. To test practically the procedures of the Schönbeck method, in particular the collection of data by photographic record.
2. To identify any problems with selection and monitoring of sites in the study area.
3. To obtain an indication of the sensitivity of the test species to air pollution levels in the study area and to determine whether it was possible to identify differences between sites.

Studies show that the distribution of lichen indicators in urban areas correlate most closely with mean levels of sulphur dioxide (SO_2) in winter, the time of year when lichens are physiologically most active.[11] The pilot survey, involving 16 sites, was carried out in the period August to September 1983 (total 10 weeks), to enable a full survey to be undertaken in the winter months (October to March).

A number of problems were identified in the pilot survey. In particular, the choice of adhesive for fixing the lichen material to the exposure boards was found to be unsuitable. Results from the lichen boards were therefore unreliable and, although differences were demonstrated between sites, no definite conclusions could be drawn from the data. Vandalism of boards was also a potential problem on unprotected sites.

The basic procedures of the method, including the photographic technique, presented no major practical difficulties and appeared to be suitable for use in the Blackbrook Valley. Accordingly a number of recommendations were made outlining the procedures for a full scale survey, which was carried out in the winter of 1983/4. Although the procedures in this survey were much improved, additional improvements were identified and these were incorporated into a second survey carried out in 1984/5. The purpose of the first survey was to investigate the suitability of the lichen board technique as a means of indicating possible air pollution gradients in a small scale survey (the Blackbrook Valley). In particular, procedures of the method would be assessed.

The remainder of this chapter is a report of the first survey.

4.2.0 METHOD

The method was carried out in three stages. These can be subdivided giving seven main procedures, summarised in Table 4.1.

Table 4.1 Lichen board methodology: summary of procedures.

Stage 1	Preparation of boards	Choice of indicator Collection of plant material Construction of boards
Stage 2	Exposure of boards in the Blackbrook Valley	Location of sampling sites Positioning of boards on site
Stage 3	Monitoring of boards	Photographic procedure Assessment of exposure effects

Details of these procedures are now described.

1. Choice of indicator. The epiphytic lichen *Hypogymnia physodes* (*Parmelia physodes* in earlier literature) was chosen as a test plant. It fulfills the main requirements of a good indicator as described in the literature.[12] It is a very commonly occurring species, found in a wide variety of habitats in unpolluted areas. It is moderately sensitive to sulphur dioxide (SO_2). When used as a bioindicator of SO_2 this enables the differentiation of damage effects to be observed over a reasonable i.e. "monitorable" period of time. Its suitability for use in studies of urban air pollution has been verified by various workers.[13,14] It has also been used successfully in a major urban bioindication programme in Berlin. [15]

2. Collection of plant material. Samples of *Hypogymnia physodes* were collected from an unpolluted site in Shropshire, approximately 60 miles (96 km) west of Dudley. The site is an abandoned quarry, which has been colonised by mixed deciduous trees, predominantly Birch (*Betula pendula*), Oak (*Quercus robur*) and Rowan (*Sorbus aucuparia*). The grid reference of this site is 386036, O.S. map sheet 126.

3. Construction of exposure boards. In the laboratory the lichen samples were cut into approximately disc-shaped pieces to fit circular recesses drilled in the boards. Each board contained ten recesses measuring 4.5 cm diameter by 0.5 cm deep. The design of the boards and arrangement of sample discs is shown in Fig. 4.1. Individual discs were fixed in position using the adhesive "Araldite".

4. Location of sampling sites. The choice of sampling sites was important to both the scope of the survey and the usefulness of the results. If differences in air pollution levels existed between sites, then it was clearly necessary to ensure that some useful basis existed for making comparisons between sites. Two aspects were considered:

1. Physical characteristics of the study area likely to affect the dispersion of air pollution.
2. Strategic areas of special importance in the study.

The two main physical characteristics influencing the dispersion of pollution are climate and topography. The orientation of the Blackbrook Valley is SSW to NNE. This is also the prevailing wind direction.[16] Potential sampling points were identified on the map on a line along the centre of the valley and along lines at right angles to it (WNW to ESE). This arrangement gave the possibility of obtaining site comparisons in relation to wind direction and also between points at similar heights on opposite sides of the valley (see Fig. 4.2).

In addition to the above pattern other sites were located in and around strategic points of interest. The specific areas of interest selected were aimed at allowing useful comparisons between sites which were either potential sources, or potential targets, of air pollution. Thus, the first category included the main industrial areas or potential single emitters. In the second category the principal area of interest was Saltwells Wood Local Nature Reserve. Based on this framework about thirty potential sampling points were identified. The actual sampling sites had then to be identified on the ground and, where appropriate, permission for access negotiated. A total of 28 sites was identified with the assistance of Dudley Council. A map and list of these sites are shown in Fig. 4.3 and Table 4.2 respectively. The Shropshire site, from which the lichen was collected, was used as a "clean-air" control site.

5. <u>Positioning of boards on site.</u> This was standardised as far as possible to minimise variations in the conditions of board exposure. At each of the selected sites the exposure boards were fixed in a vertical position facing north, at a height of 1.5 metres above ground. In the Schönbeck study the exposure boards were attached to purpose-made steel posts using wing nuts, which were easily unscrewed and enabled boards to be taken to a vehicle for photographing. This approach was considered to be unsuitable for the Blackbrook Valley study. Firstly, it was unnecessarily time-consuming to remove boards for photographic purposes. Secondly, in order to minimise the risk of vandalism, it was necessary for the boards to appear as unremovable and unobtrusive as possible. For these reasons the boards were tied securely to existing permanent features on site, such as fences, trees or posts. Wherever

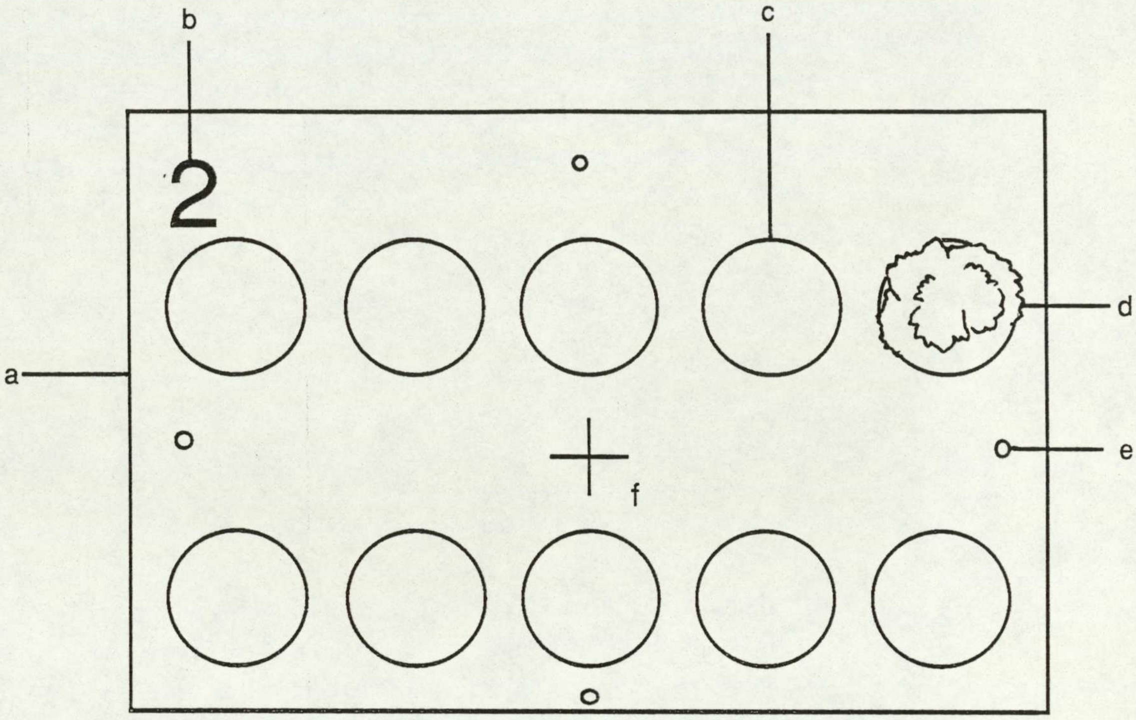
possible these were in private gardens or in the grounds of official premises, such as schools or factories. Plastic-coated wire was used to prevent the possibility of metal contamination.

6. Photographic procedure. The survey boards were exposed to the air in the Blackbrook Valley from 21 December 1983 to 6 June 1984, a total of 25 weeks. The boards were photographed before the exposure period (20 December) to provide a set of control photographs; they were then re-photographed at intervals of between three and six weeks until the end of the survey. The length of the intervals varied depending on the amount of change observed in the lichen discs and on the weather conditions.

Photographs were taken with a Pentax single-lens reflex camera and a 50 mm lens using Kodacolor II print film. An electronic flash unit was used to provide uniform lighting conditions. The focussing distance was the minimum which enabled the whole of a board to be included in a single frame (0.75 m).

7. Assessment of exposure effects. At the end of the survey each board was represented by a set of photographs consisting of (i) a control and (ii) a sequence of seven photographs corresponding to weeks 3,9,13,15,17,19 and 25 of the exposure period. At the end of the survey all the photographs were examined in turn. The extent of damage in each lichen disc was determined subjectively by noting the colour of the lichen thallus and estimating the proportion of apparently dead plant cover. In order to simplify the subsequent analysis of results, the data from the photographs was recorded directly onto standard score sheets, an example of which is in Appendix D.

Fig 4.1 Details of lichen board design.



KEY

a timber board (30 x 20 x 3 cm)

b site identification number

c recess (4.5 cm diameter x 0.5 cm deep)

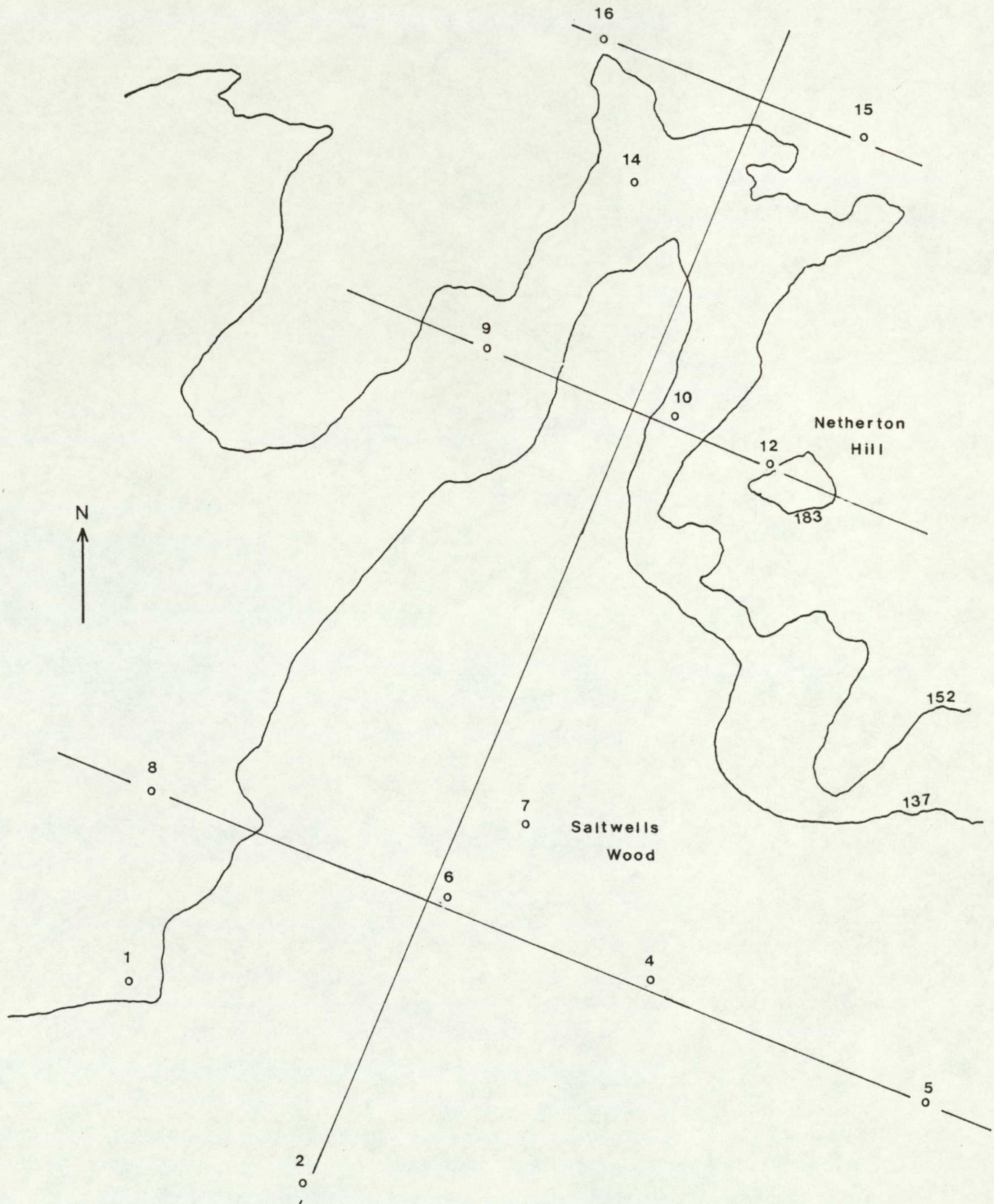
d lichen disc fixed in position using Araldite

e holes in top and sides giving choice of attachment points for wire

f cross marking centre of board aiding focus and framing of photographs

Source: based on design used by Schonbeck[10]

Fig. 4.2 Blackbrook Valley: map showing location of sampling sites in relation to topography and prevailing wind direction.



Note o sampling site
scale of map 1: 20000
contour heights shown in metres

Fig. 4.3 Lichen Board Survey 1: location of sampling sites.

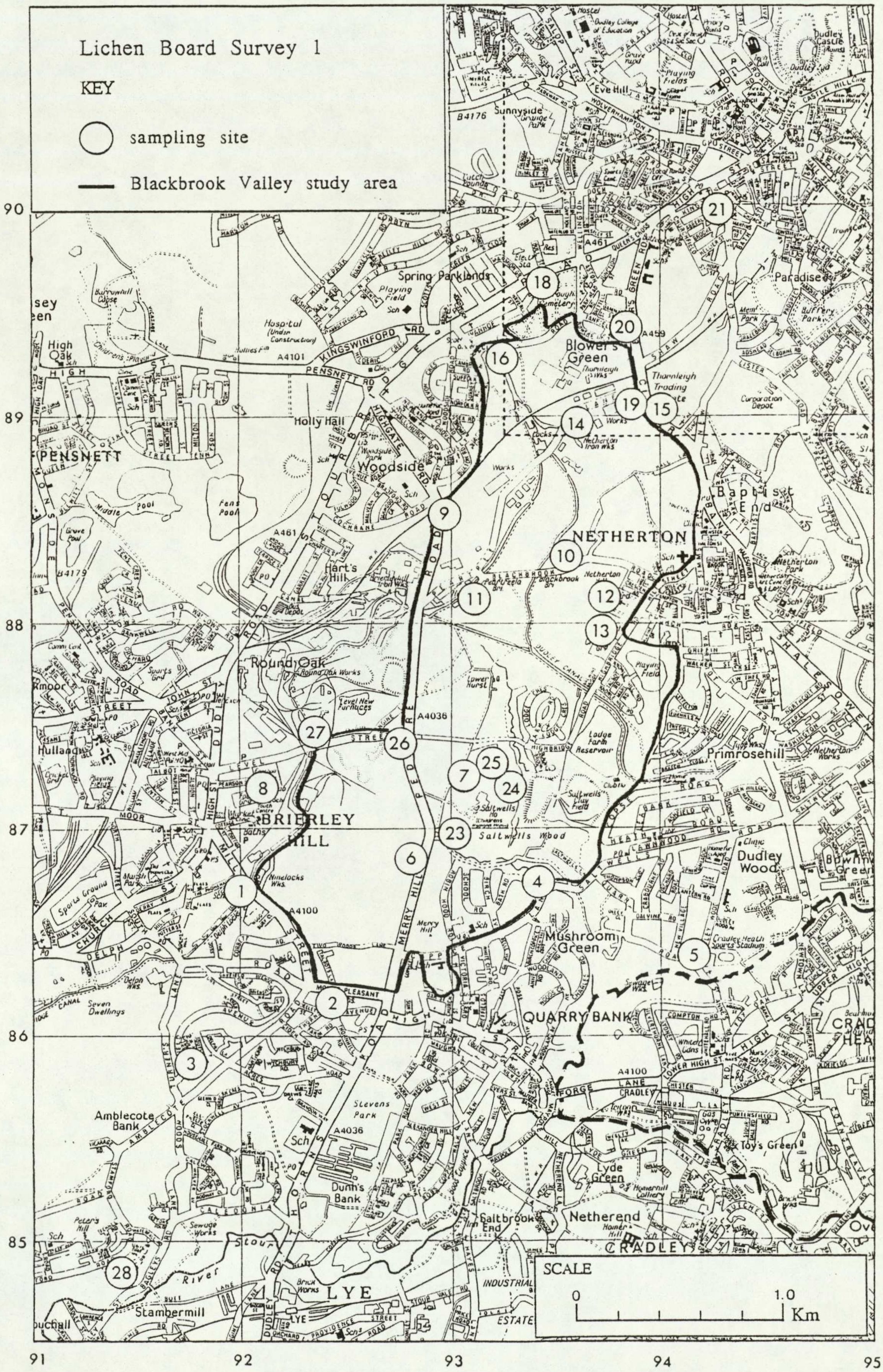


Table 4.2 Lichen Board Survey 1 - List of sampling sites

Site	Location	Address	Map Ref
1.	Brierley Hill C P School	Mill Street	920 867
2.	Mount Pleasant Primary School	Mount Pleasant	925 862
3.	private house	Goldthorne Walk	917 859
4.	private house	56 Bath Road	934 867
5.	Methodist Church	Quarry Road	943 864
6.	Robin Hood Inn	Pedmore Road	928 869
7.	woodland	Saltwells Wood LNR	931 873
8.	Olympia Testing Co Ltd	Level Street	922 872
9.	R.W. Priest Ltd	Pedmore Road	929 884
10.	field	Blackbrook Road	935 883
11.	Roof Units Ltd	Blackbrook Road	931 881
12.	Saint Andrews Parish Church	Church Road, Netherton	937 881
13.	Yew Tree Hill (First) School	Highbridge Road	937 880
14.	Lloyds Steel Works	Peartree Lane	935 889
15.	Herman Smith Ltd	Cinder Bank	940 890
16.	private house	32 Clee Road	932 893
17.	wasteground	Hall Lane	940 887
18.	Dudley Cemetery	Stourbridge Road	934 896
19.	C. Brown Ltd	Peartree Lane	938 891
20.	private house	74 Blowers Green Road	939 894
21.	Home for the Aged	Abberley Street	942 900
22.	not placed		
23.	woodland	Saltwells Wood LNR	930 870
24.	woodland	Saltwells Wood LNR	932 873
25.	woodland	Saltwells Wood LNR	932 874
26.	Midland Oak Steel Training	Level Street	928 874
27.	canal bank	Level Street	923 875
28.	private house	33 Barn Owl Walk	914 848

* O.S. Map Sheet 139 (Section SO) 1:50000 Landranger Series

4.3.0 REVIEW OF METHOD AND ASSESSMENT OF DATA

The purpose of the survey was to investigate the use of lichen boards as a means of indicating possible air pollution gradients in the Blackbrook Valley, and hence the value of the method as a means of collecting data useful to the Nature Conservancy Council. The success of the method is based on the outcome of several processes. Assessment of the methodology therefore divides into three stages, which in chronological sequence are:

Table 4.3 Assessment of methodology: key stages

1.	Data collection	- the procedures of setting up and monitoring the lichen boards as outlined in the method procedures 1 to 6.
2.	Data processing	- the procedures associated with the extraction of required data i.e. by assessment of the photographs as described in the Method procedure 7.
3.	Data analysis	- statistical analysis and interpretation of the results.

The most important of these stages is the second. Some of the problems of the method, e.g. the effects of vandalism, were apparent or suspected at the outset of the survey. However, although they did not affect the practical implementation of the survey, they were important because of their effect on the quality of results obtained from the photographs. For this reason Stage 2 will be discussed first; the results section will then be presented and discussed. The findings of these two aspects, in relation to the process of data collection, take the form of practical recommendations for a second survey.

4.3.1 The photographic method

The collection of data by photographic record provides a number of advantages, namely:

1. A permanent visual record of events being monitored. Unlike instantaneous observations made in the field, the observer can go back to these.
2. As a consequence of the above, a set of data which can be assessed independently by different observers or by different methods.
3. An efficient way of collecting data, largely independent of weather conditions, and requiring a minimum of time. All sites can be visited in one day. Furthermore because the record is permanent the technique enables postponement of data assessment until convenient. The process of recording data is therefore more likely to be accurately/carefully done.

4.3.2 The scoring procedure

The first stage in data processing is to decide exactly what information is to be extracted from the photographic record. This is determined by the requirements/objectives of the survey, which should be precisely defined beforehand. In the present survey, which involved testing the suitability of the method, there was unavoidably a degree of trial-and-error in determining what this information should be. The process of scoring the photographs was therefore aimed at maximising the amount of data available for analysis, and particularly for checking the various aspects of the methodology.

The basis of the scoring procedure was to use colour differences as a means of estimating the proportions of living (healthy) and non-living (dead or damaged) lichen. By comparing the photographs for each of the different weeks with the control, the progress of lichen damage with time could be assessed.

The characteristic colour change of *Hypogymnia physodes*, in response to air pollution, is from green or (greyish green) to white. The white coloration results from the destruction, and hence bleaching, of chlorophyll in the algal cells of the lichen thallus. The damaging effect of air pollution on lichens is primarily due to sulphur dioxide.[17] The action of sulphur dioxide on chlorophyll can also result in the formation of breakdown products called phaeophytins, which are brown in colour.[18] Although brown colour was observed in the survey on some discs, such discoloration can also be caused by other factors such as disease, or infection resulting from accidental damage. Therefore the areas of brown and white tissue were recorded separately.

The values recorded on the score sheets represent percentage cover estimated from lichen discs as viewed; they do not relate to the original amount of material present. For each monitoring period the percentage of each disc surviving from the start of the survey was also assessed by comparing with the control photograph. This amount was subtracted from 100 and recorded separately as percentage lost.

It was important to define the procedure for scoring to ensure consistency of treatment of the photographs. Little guidance on this was found in the literature. The development of a suitable scoring procedure was one of the aims of undertaking the first survey. There were two principal decisions or problems to be resolved, namely:

a) Level of detail required.

b) Proposed method of estimation.

Level of detail required. The amount of detail ultimately required by Nature Conservancy Council may not be very great. However, in a preliminary trial, it seemed valuable to obtain maximum information from the lichen survey. A high level of detail was therefore chosen. Percentage cover of green, white and brown tissue were estimated to the nearest 5%. In the early weeks of the survey it was of interest to identify the onset of colour changes in the lichen discs. For this purpose a value for the smallest significant level of damage was required. In practice it is difficult, and pointless, to try to estimate accurately very small amounts of damage e.g. 1 or 2%. Accordingly small levels of damage greater than 0% but less than 5% were recorded as 2.5%. The value of 0% was reserved to indicate no difference from the control photograph. The same principle was applied to levels of damage at the top end of the scale i.e. giving scores of 95%, 97.5% or 100%. The purpose of using both a column for percentage green and for percentage white was purely for convenience. Depending on the relative proportions of these it is often easier to estimate percentage green first or *vice versa*.

Using the above system of scoring proved to be very time-consuming, requiring approximately half a minute per disc or 5 minutes per board (total more than 17 hours for all photographs). Until full statistical analysis had been carried out, it was difficult to assess whether this level of detail was necessary in the data. To decide whether this was necessary, two aspects needed to be considered.

Firstly, was the level of detail needed by the statistical analysis. This is dependent on the final purpose of the study. The main objective of using the lichen board method in the Blackbrook Valley was to establish whether the method provided a suitable means of detecting differences in the pollution levels between sites in a small scale survey. In theory one could measure exposure time to a given level of pollution damage, for example 50 percent lichen death. A survey of this kind would require a calibration to be established between the test species and known doses of the air pollutant under study. Leblanc and Rao[19] observed lichen and moss transplants in the heavily polluted area of Sudbury, Ontario and showed that injury symptoms in *H. physodes* could be correlated with specific concentrations of sulphur dioxide. Elaborate laboratory work of this type was outside the scope of the present research. The overall progress of lichen death was therefore of interest. This contrasts with other studies using lichen boards in which only the final levels of damage were measured.

The second aspect to be considered is the level of detail which it is possible to obtain. This is influenced mainly by the photographic method, and is discussed later.

Methods of estimation. There were 2 possibilities:

a) To use an objective or routinised technique for measuring areas of damage, for example a light pen or planimeter.
b) To use subjective estimation (by eye).

It was decided to estimate the photographs by eye. On purely practical grounds this would be quicker than by using objective techniques. It was also necessary to be aware of the use for which the data was being collected and to match the method of estimation to the degree of precision which was possible. In this respect, the size of the photographs was not sufficient to enable the use of sophisticated methods with any degree of confidence. In addition, the nature of the areas being measured was not as clear-cut as first appeared. Colours merged in to each other and there was some variation in colour quality and image size in different batches of photographs.

For the reasons outlined above the accuracy of an objective method was likely to be limited.

4.3.3 Validation of data

There were three main sources of error in the data:

1. The photographs.
2. The objectivity of scoring.
3. Variations in the lichen material.

A number of problems related to these sources were apparent during the scoring process and are discussed in the following sections.

1. The photographs

Size of photographic image. In the survey method used by Schönbeck and others the lichen discs on each exposure board were photographed individually at each monitoring interval. This procedure was rejected in the present study for two reasons:

a) It would require individual labelling of discs, either at the time of photographing or as a permanent design feature of the boards. The first option was too time-consuming. The second option would have the disadvantage of making the boards too conspicuous.

b) It would increase the cost of monitoring by a factor of 8 - 10 times.

Although data was scored from prints of fairly large size (100 by 150 mm), recording at the chosen level of detail was difficult. Increased image size was needed to improve the speed and accuracy of scoring. There were a number of ways in which the image could be improved. Further enlargement of prints was one possibility. However, this approach was considered to be both costly and cumbersome. Nor would it have overcome the essential problem, which was lack of detail on the negative. An effective compromise between the German approach and the present one would be to photograph the boards half at a time. This would enable the camera to focus closer, giving a larger image on a standard sized print. Monitoring time and costs would be increased proportionately. However, the main disadvantage with this approach would be the minimum focussing distance, which is limited when using flash. The use of a longer focal length lens (135 mm) is another possibility which would enable enlargement of image size without decreasing physical distance between camera and board. This approach was tested with satisfactory results.

Colour fidelity of photographs. Variation in the colour quality of photographs was found in both the pilot and main survey. Use of a standard colour strip (Kodak Gray Scale) in each photograph did not appear to overcome the problem. It was consequently difficult to make a consistent colour distinction between live and dead material in different batches of photographs. Those for week 19, for example, had an overall blue colour bias which was probably the result of a processing fault. The scores for percentage white obtained from these were consistently lower than scores for the previous monitoring period (week 17). From field observations, made at the time of monitoring, it seems likely that the condition of the lichens was similar to the previous period. It would therefore seem more reliable to leave out week 19 data in any calculations. Presentation of data in the results section has been constructed on this basis.

2. Objectivity of scoring

The data for each board from 1 to 28 was scored subjectively by a single observer (the author) in the correct chronological sequence of monitoring events, i.e. starting with the control photograph (week 0) and proceeding through to the final date (week 25). A random sample of 26 photographs (representing 10% of the total data) was re-scored for comparison with the results obtained in the first assessment. Statistical analysis of these results showed that the scores were reproducible to within ±10%. Results are in Appendix D.

3. Variation in lichen material

Loss of material. There were two distinct causes of losses from lichen discs.

a) Accidental. In its natural surroundings *Hypogymnia physodes* is only loosely attached to its substrate. Fragments of the lichen thallus break off naturally, particularly after periods of desiccation or during severe winds. When used in the bark-disc method Schönbeck observed that "withered parts of the lichen frequently drop off after some time."[20] The extent of such losses in the present survey would be influenced by various factors, in particular the condition of the lichen thallus (living or dead) and its attachment to the substrate (disc with or without bark).

b) Non-accidental (vandalism). The pilot survey had confirmed that losses of lichen material by deliberate (human) interference could be expected in the study area. Fortunately in the survey these were only at low levels. There were two types of damage. Firstly there was damage involving whole boards. This occurred in the period immediately following positioning of the survey boards on site; one board was completely destroyed and another moved during this period. Secondly, there were isolated incidents of partial damage to boards which occurred throughout, but more particularly towards the end of, the survey period.

Losses involving whole boards were fairly serious and could best be overcome in future surveys by careful choice of sites and positioning of boards. Subsequent losses were less serious but also less controllable. At the end of the survey period a total of two boards had been lost, including the clean air control. Of the remaining boards, 17 from 26 had suffered losses of one or both types described above. The board results were tested to assess whether losses of material affected the reliability of scores (see Appendix D). For each board where losses had occurred the mean percentage damage, calculated over all discs, was compared with the mean score for discs without lost material. The likely cause of lost material was also evaluated from the photographs and from notes made in the field. In most cases the difference in mean scores was within 5%. Two boards showed differences of greater than 10% (maximum difference 16%). Boards showing differences of greater than 5% all contained one or more seriously vandalised discs (60 to 99% lost). When such discs were eliminated from the calculations the difference between board means, calculated with and without lost material, were all within $\pm$10%.

It was clear from the above that extensive losses due to deliberate interference could have a significant effect on the reliability of data and should be eliminated from calculations. On the other hand, losses resulting from accidental causes were generally small and did not appear to have a serious effect on the data. Recognition in the field was the best guide to identification of seriously vandalised discs. However, at low levels of damage, it was not always possible to to distinguish between accidental and non-accidental loss. There is therefore a good case, in surveys of this kind, for setting a maximum damage level as the criterion for inclusion of data. In the present case discs with greater than 50% lost were discounted from any subsequent calculations.

<u>Presence of bark.</u> When using lichens as bioindicators of SO_2 it is important to eliminate as far as possible other variations in environmental conditions. In particular this involves maintaining the original conditions of the site. The bark-disc removal technique developed by Brodo preserved a core of the underlying substrate resulting in no noticeable effect on the lichen.[21] Following Brodo, the bark cutting method was adopted and modified by various workers.[22,23] The removal of bark-discs by means of special cutting tools is unnecessarily destructive and time-consuming. Work by other researchers[24,25] has confirmed that bark-free lichen can be successfully transplanted using non-volatile resin adhesives, such as "Araldite", provided that contact with the lichen itself is minimised.

The bark-free approach was adopted in the present survey as material was collected from Forestry Commission land where deliberate cutting of living trees was undesirable. It is possible that removal of lichen without bark could damage the thallus and predispose it to harmful effects including damage by air pollution. Therefore some lichen was collected with bark. During preparation of the boards a record was kept to enable comparison of discs with and without bark. The final scores for percentage live cover have been compared (Appendix D). There was no significant difference between the scores, suggesting that the presence or absence of bark did not affect results.

<u>Effect of brown colour</u> The amount of brown colour observed on discs was generally small; no greater than 16% (mean 10.5%) for any board. The

distribution of brown colour occurred usually at the edges of the bark-discs and where fragments of lichen were trapped in the adhesive. These observations indicate that the lichens were affected by the adhesive at the cut edges. There was therefore a possibility that there could be differences between discs on bark and those which were bark-free, since the latter would be subject to closer contact with the adhesive.

Analysis of variance was carried out on the final (week 25) scores to assess whether brown colour was associated with the presence or absence of bark and, if not, whether it could be attributed to other factors such as Araldite or cutting. The analysis showed that percentage green values for discs with or without bark were not significantly different. There was similarly no significant difference in percentage brown for discs with or without bark. For the purposes of calculations, it was reasonable to disregard brown as a separate damage category and include any such tissue as non-green.

Summarising from the above discussions, it can be seen that the main sources of error in the survey data resulted from problems with assessing the photographs: in particular the level of detail recognisable, colour quality and the objectivity of scoring. A suitable method of increasing the image size, and hence detail, would help to overcome these problems. Factors relating to the condition of the lichen material, and hence variations between discs, were comparatively insignificant: i.e. loss of material (<50%), presence or absence of bark, and percentage brown.

4.4.0 RESULTS

4.4.1 Overview

This section summarises the results of the survey, and highlights the main points of interest.

The survey period was from the end December 1983 to early June 1984, a total period of 25 weeks. Due to a number of difficulties the period of the survey did not coincide exactly with the main winter period (October to February) as originally intended. At the end of the survey the mean level of damage (percentage non-green) shown by the boards was between 12 and 56% (mean 31%). The progress of lichen damage is shown by Table 4.4 and Fig.4.4.

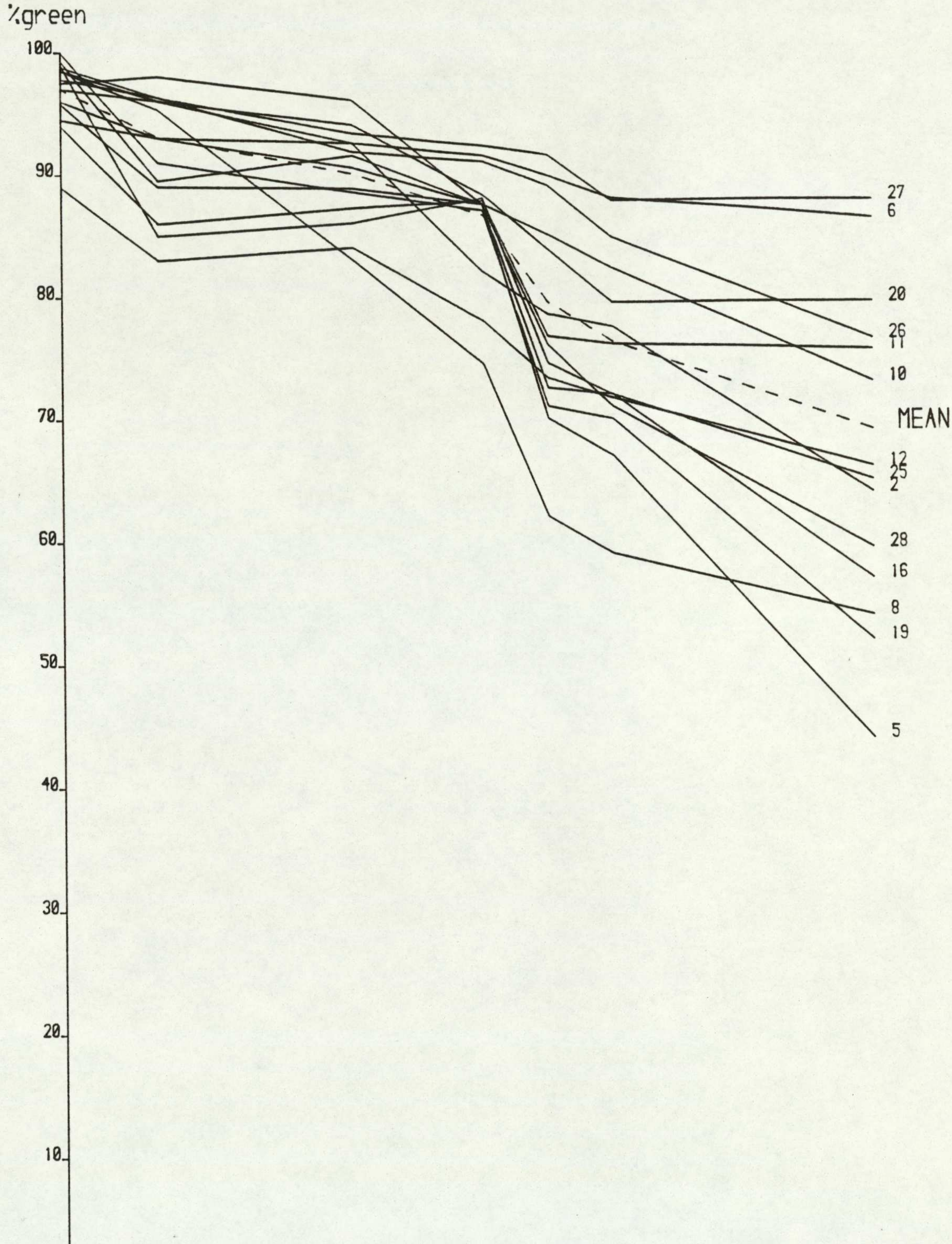
Table 4.4 Summary of lichen data (mean all boards)

Week	0	3	9	13	15	17	25
%green	97.0	93.1	90.0	86.6	79.5	76.3	69.1
s.d.	(5.2)	(7.2)	8.5	9.4	12.1	12.4	15.9
n	260	260	259	257	256	246	244

Note n = no. of replicates excluding discs with losses >50%

Full data for all boards is in Appendix D.

Fig. 4.4 Lichen Board Survey 1: graph showing range of lichen damage of different boards with time.



4.4.2 Differences between boards: progress of lichen damage

The graph in Fig. 4.4 shows the progress of lichen damage for all boards. A similar pattern was observed among the individual boards. The graph shows that the main changes occurred at roughly the same times. There are three more or less identifiable stages.

stage 1	Week 0 to 13	Slow decline or little change
stage 2	Week 13 to 15	Rapid decline
stage 3	Week 19 to 25	Second period of slow decline

The initial period of little change resembles the so-called "lag phase" characteristic of many types of biological responses. Among the survey sites there was typically either a continuous slow decline in percentage of undamaged (green) lichen, or an initial drop, followed by a longer period of little change. In the early stages of the survey it was expected that the lichen transplants might show some damage in response to the environmental conditions of a new site. On the other hand, a rapid decline in living tissue at this stage would have indicated that the test species was too sensitive to the air pollution levels in the study area and an unsuitable choice of indicator.

The increase in rate of damage to lichen discs after a period of 9 to 13 weeks suggests that a critical or "threshold" dose may have been reached. For most sites this was the period when the main onset of damage symptoms occurred. Not shown on the graph in Fig. 4.4 is the suspected halt in further damage, which occurred in the period 17 to 19 weeks. As previously explained (section 4.3.3) there was some doubt as to the validity of scores obtained for week 19. During the period of weeks 11 to 15 the lichens became desiccated due to a prolonged spell of dry weather. In this condition respiration and photosynthesis would be severely reduced and any effects of air pollution suspended. The final period of change occurred after a period of rain.

There was obviously some variation in the pattern of damage at different sites. Where there was a high level of final damage (low percentage green) the three or four stages described here are easily recognizable e.g. sites 5, 19 and 28; for sites with low levels of damage these stages were still more or less evident, e.g. in site 23, although scarcely at all for site 6.

In the present survey there was never any intention to relate levels of lichen damage quantitatively to actual air pollution concentrations. This would have required detailed calibration of pollutant and indicator. It is nevertheless worthwhile to speculate on the reasons for differences in the gradient with time for sites with similar levels of damage. For site 5 (final score 44% green) and site 19 (final score 52% green) the main period of change occurred in the second half of the survey period. In site 8 (final score 54% green) the greatest damage occurred in the first half of the exposure time. These differences could reflect different patterns of pollution dispersion, perhaps related to wind direction, or to the effects of different pollutants. Information on the specific cause of the pollutant effect could be determined only by detailed investigation of internal changes in the lichen thallus.

4.4.3 <u>Differences between boards: final scores</u>

The main comparison of data between sites is provided by the final %green scores.

Table 4.5 Lichen board Survey 1 - final %green scores

Site	1	2	3	4	5	6	7
%green	-	64.0	78.5	67.5	44.0	86.3	73.3
	8	9	10	11	12	13	14
	54.0	69.0	73.0	75.6	66.1	70.6	70.0
	15	16	17	18	19	20	21
	69.4	57.0	=	67.0	52.0	79.5	78.5
	22	23	24	25	26	27	28
	-	79.0	65.0	65.0	76.5	87.8	59.5

Range 44 to 88%
Mean 69.08%
s.d. 15.9%

Notes = board not placed
- data missing

The above results are shown on the map overleaf (Fig. 4.5). The data for different sites is also represented according to the degree of deviation from the mean (Fig. 4.6). Over half of sites are within 0.5 standard deviations (s.d.) of the mean value and can be taken to represent the average response to conditions in the area. These sites form two groups:

a) In the south, the five sites in and around Saltwells Wood.
b) Centrally and north, seven sites in the industrial area of the Blackbrook Valley.

Fig. 4.5 Lichen Board Survey 1: map of final %green scores.

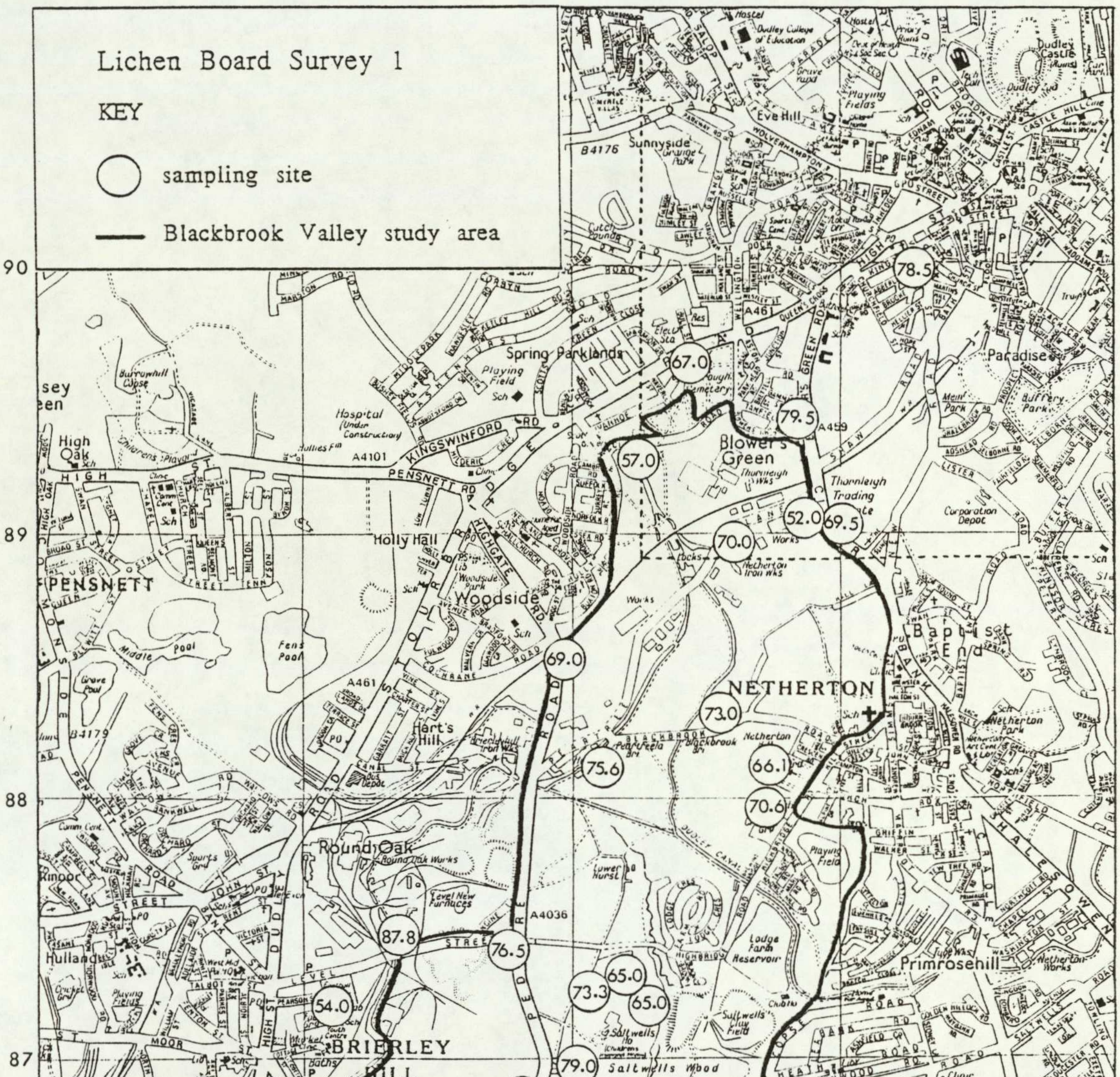
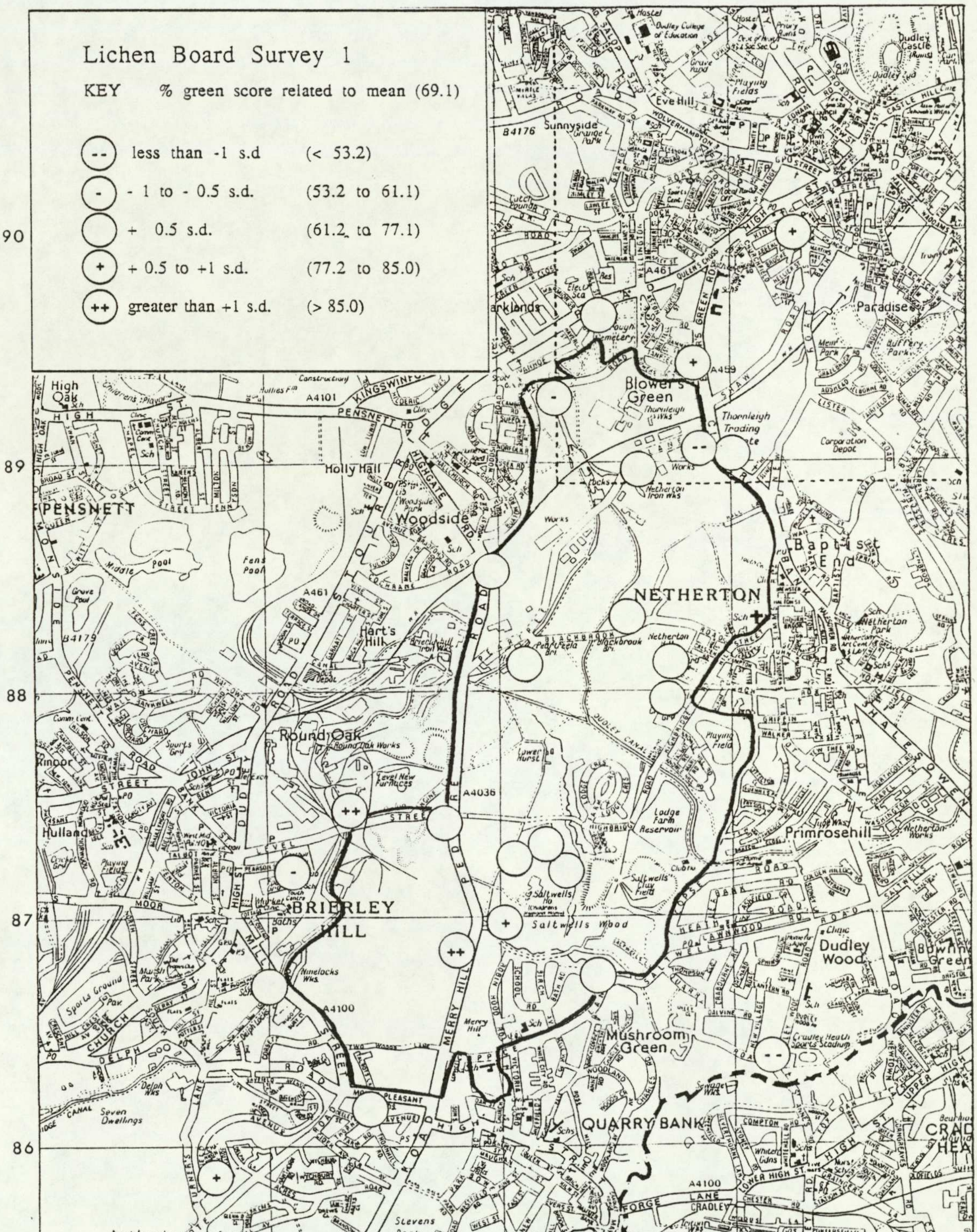


Fig. 4.6 Lichen Board Survey 1: final %green scores grouped in relation to the mean.



Of the remaining sites a further seven are within 1 s.d. of the mean (69.1%). Above average levels of percentage green are shown by two sites in the north (site 18 and site 21) and one in the south (site 3 in Withymoor Village). Below average percentage green was found in the north at site 16 (Clee Road) in the west at site 8 (Level Street) and in the south at the local control site 28. It is interesting to note that the lowest levels of damage (greater than mean +1 s.d.) occurred south west of the Blackbrook valley at site 6 (Pedmore Road) and site 27 (canal alongside former Round Oak Steel Works). The two sites showing the highest levels of damage (less than mean -1 s.d.) were site 5 (south east of the study area) and site 15 (top of Peartree Lane).

4.4.4 Controls

The clean-air control board in Shropshire was lost at an early stage in the survey. From the relevant literature there was no reason to expect any significant adverse effect of the method on the lichen, e.g. due to cutting, or the use of adhesive. Even if some effect could be shown in the present survey the relative differences between sites should be unaffected.

Site 28 formed a local or "internal" control board for the study area, being positioned 2 to 3 km SW of the main sites. The purpose of the internal control was to obtain a measure of regional pollution levels from the prevailing wind direction. Results showed that the levels of damage at this site were relatively high in comparison with the remainder of the study area. If the value for lichen damage is representative of the area outside the Blackbrook Valley then it is important to consider whether the levels obtained in the study area as a whole have any significance or whether they show evidence of masking by regional effects.

4.4.5 Summary

The survey showed that *H.physodes* collected from a relatively clean-air site was damaged by air pollution levels in the Blackbrook Valley. The main changes in colour of the lichen discs occurred after the period of 9 to 13 weeks. More than half of the lichen boards were within 0.5 s.d. of the mean value of boards. The extremes of the damage range were found mainly in sites at the edges of, or outside, the main study area.

There appeared to be no obvious pattern to the differences between sites. Statistical analysis was carried out to test correlation between damage levels and environmental factors such as wind direction, height above sea level, and proximity to nearest emission source. No significant results were found (see Appendix D).

The internal control indicated that the effects of regional air pollution levels around the Blackbrook Valley may be more significant than local influences on the health of vegetation.

4.5.0 ANALYSIS OF LICHEN BOARD TECHNIQUE

4.5.1 Outline

The basic methodology of the lichen board technique presented no major practical difficulties when applied in the Blackbrook Valley. However, as outlined in sections 4.3.1 to 4.3.3, the survey highlighted various problems related to the reliability of results which were a consequence of the methods used. In particular the colour quality and image size of the photographs were recognised as important limiting factors on the success of the scoring process. If a further survey was to be attempted, a number of improvements would be necessary.

The problems and possible sources of errors in the survey data are summarised below.

Table 4.6 Lichen board methodology - summary of problems

1. Data collection	- inherent variation in lichen discs due to a) presence/absence of bark b) age of thallus c) substrate species d) effect of cutting - acquired variation due to vandalism
2. Data processing	- insufficient detail obtainable due to size and quality of photographs - scoring process slow and unnecessarily precise
3. Data analysis	- more sites needed to increase sampling area and/or density - controls inadequate

Methods for resolving the above problems were considered. Modifications were proposed for the following aspects:

1. Board design.
2. Collection of lichen samples.
3. Number of sites.
4. Controls.
5. Scoring.

The detailed recommendations proposed for improving these aspects are discussed in the next section, using the same headings as above.

4.5.2 Recommendations for a second survey

1. Board design

There were two main ways that the board design contributed to the problems outlined in Table 4.5.

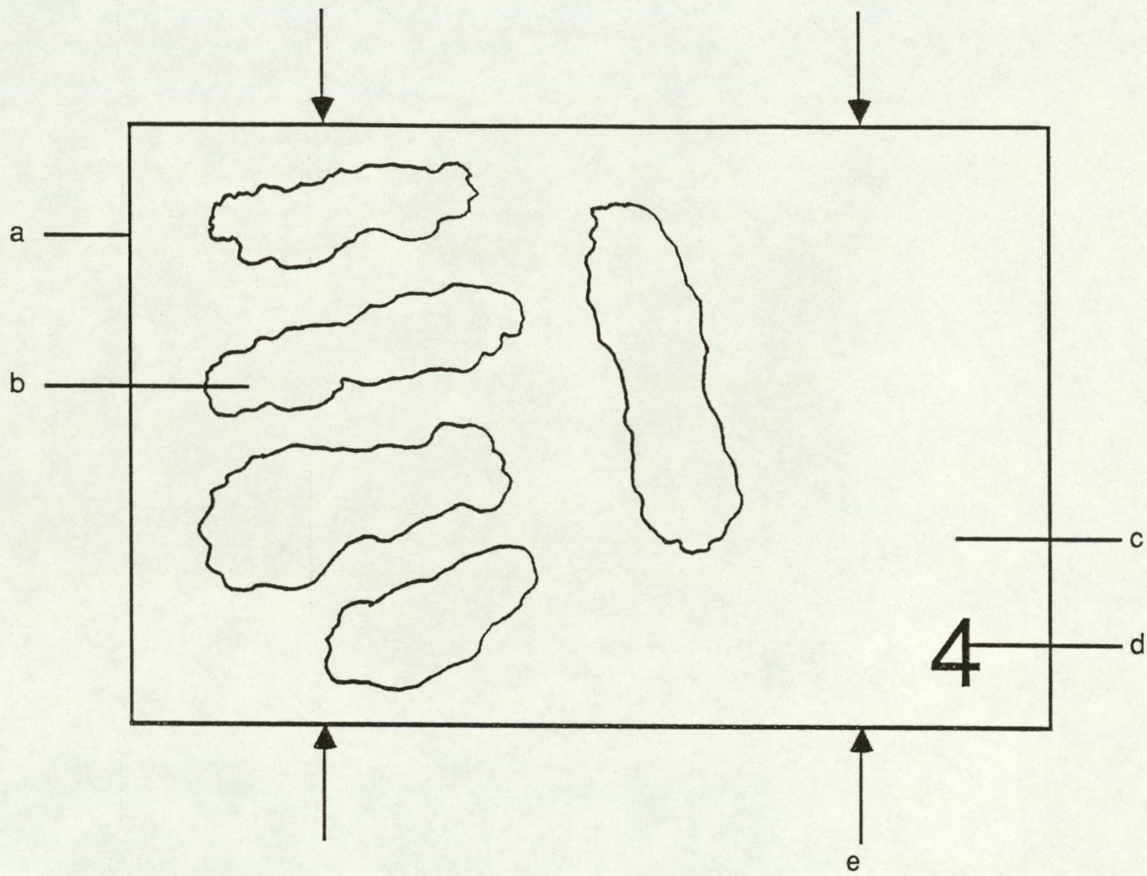
a) Size and arrangement of discs. This was the main factor restricting the amount of information obtainable from photographs of whole boards. The large size of the board, in comparison with the discs, was wasteful of space.

b) Cutting of discs. The use of discs and recess holes was time-consuming and necessitated cutting of the lichen thalli to a pre-set size.

A further consequence of the above two features was that the regular pattern of replicate discs made the boards conspicuous. This probably contributed to the risk of vandalism. A smaller, less conspicuous design of board was required. A new design was developed as shown in Fig. 4.7. It differed from the previous design in the following ways:

1. Smaller size.
2. No pre-shaping of discs.
3. No recess holes.
4. Number of replicates reduced to five.

Fig. 4.7 Details of modified lichen board design.



KEY

a timber board (15 x 10 cm)

b lichen fixed in position using Araldite

c margin for attachment of information panel (date card/Kodak Gray scale)

d site identification number

e holes (drilled vertically through board) for attachment of wire

The advantages of the modified board design are as follows:

Firstly, preparation of boards would be greatly simplified and therefore quicker. The smaller size of the boards would allow more economical use of materials both in terms of costs (materials and labour) and in terms of the ecological impact on the collection site.

Secondly, the design eliminates pre-shaping of discs, minimising the risk of variation in the lichen material due to cutting and possible effects of Araldite.

Thirdly, the quality of the photographs would be greatly improved. The smaller size of the board, combined with the use of a longer focal length lens for photographing, would enable much larger images of lichens to be obtained on standard-sized prints. This, in turn, would overcome the main problems with the scoring of the photographs: colour quality, image size/detail observable.

2. <u>Collection of lichen samples</u>

Many rural areas, including parts of Shropshire, are not particularly clean; they may only be relatively pollution-free. Nevertheless, the condition and abundance of the growth of *Hypogymnia physodes* at the Shropshire site indicated that the material used was healthy. However greater standardisation in the collection of this material was desirable to eliminate differences in thalli, in particular to ensure that lichens of a similar size, i.e. similar age, were taken. It was also desirable to restrict the collection of material to a single tree species, as different bark substrates have different pH values.

3. Number of sites

The distribution of sites in the first survey left some noticeable gaps, particularly on the east and west sides of the valley. The number of sites should be increased to enlarge the total area of the survey and also to fill in gaps around strategic areas. This would allow more accurate interpolation of results. The maximum number of sites which could be accommodated comfortably in the survey routine was estimated to be 40. Regarding the positioning of these boards on site: the present method of selecting and safeguarding boards was reasonably effective. No re-positioning of boards at existing sites would be necessary. New sites would make use of schools, private gardens or industrial premises if possible, since these had proved to be the most secure.

4. Controls

An increase in the number and type of controls was required. In particular the following aspects needed to be considered.

a) Clean-air control. The clean-air control was lost in the present survey. Hence there was no means of assessing the level of damage to the boards which could be attributed to the effects of the Blackbrook Valley. In future a minimum of two or three boards should be placed at the Shropshire site for this purpose. It is unlikely that all would be vandalised.

b) Method control. The clean-air control is in effect only a partial control, as the transplanting of lichens from their substrate to a different location, even within the same site, changes the surrounding environmental conditions.[26] A truer test of any effects of the method (due to removal, use of adhesive etc.) would be achieved by removing the lichen thallus and replacing it exactly *in situ* using Araldite. This could be done for a small number of identifiable lichens (3 or 4), and would provide an additional check for the Shropshire site in the event of all the "clean-air" controls being lost.

c) Effect of moisture. In the present survey it seems likely that drying out of lichens was responsible for a (temporary) suspension of damage effects. The effect of wetting/drying can be checked by placing extra control boards at Aston: one board to be exposed to the air as normal, one under cover protected from the rain, and duplicates of the two above to be regularly sprayed with water.

5. Scoring

Despite the improvements which would be achieved in the photographs, as a result of adopting the new board design, the scoring method was too time-consuming and clumsy for practical use. A simple, more efficient method was required. The process of scoring could be simply speeded up by reducing the degree of precision required e.g. estimating damage to the nearest 10% instead of 5%. However, speed was not the only factor to be considered. Table 4.7 shows an alternative German scoring system which was considered.

Table 4.7 Scheme for scoring lichen damage

Category	Damage range	Mean value (%)
0	0 - 6.0	3.125
1	6.5 - 18.5	12.5
2	19.0 - 31.0	25.0
3	31.5 - 43.5	37.5
4	44.0 - 56.0	50.0
5	56.5 - 68.5	62.5
6	69.0 - 81.0	75.0
7	81.5 - 93.5	87.5
8	94.0 - 100.0	96.875

Source: Prinz and Scholl(27)

The above scheme offered a number of advantages in relation to the Blackbrook Valley study. Firstly, the scores are not estimated accurately but are allocated to a category based on the relevant damage range. This cuts down the time taken for scoring. Secondly, the system allows for the fact that, when scoring, observers tend to estimate areas (subconsciously) using convenient fractions, e.g. quarters and eighths. The mean values of each category correspond to these familiar units: 25% 50% 75% etc. Thirdly, the classification recognises the importance of recording lower amounts of damage i.e. the "smallest significant level" (discussed on p.112) at the extremes of the scale.

4.6.0 CHAPTER SUMMARY

The first lichen board survey provided an opportunity to make a detailed assessment of the technique and practical problems of the methodology. As a result of this assessment clear recommendations for improvement of the method were put forward.

In terms of the measurement of air pollution in the Blackbrook Valley data from the survey was somewhat limited. In order to arrive at any conclusions it would be valuable to obtain further data. In summary it was decided to carry out a second survey, which incorporated the improvements recommended above. This was carried out in the winter of 1984/5 and is described in the next chapter.

CHAPTER 5

LICHEN BOARD SURVEY 1984/85

CONTENTS:

5.0.0 OUTLINE

The following is a report of the second lichen board survey, which was undertaken in the period October 1984 to April 1985. It begins with a description of the method (section 5.1). The results are presented in section 5.2.

As summarised in the last chapter, the first survey had provided an opportunity both to assess the lichen board technique and to obtain some data on air pollution effects in the Blackbrook Valley. The purpose of the second survey was

1. To apply and assess the improvements to the method outlined in the previous chapter.
2. To use the data obtained to fill in gaps in information in the first survey; in particular relating to the controls.
3. To obtain a second set of data for the Blackbrook Valley study area and to compare the first and second sets.

These objectives form the basis for subsequent assessment of the results (section 5.3). The final part (section 5.4) of this chapter summarises the major findings of the two lichen board surveys, and discusses the conclusions of the survey lichen board study as a whole.

5.1.0 METHOD

The survey was carried out according to the recommendations outlined in section 4.5.2. The following is a description of the procedures, using the same headings as in the Method for Survey 1 (section 4.2).

1. Collection of plant material. Samples of *Hypogymnia physodes* were collected from the same Shropshire site as in Survey 1. To minimise possible variation in the lichen, resulting from differences in the underlying substrate, samples were taken from only one tree species, namely Birch (*Betula pendula*). This was the most abundant tree species on the site. The material selected was in the form of lichen-covered twigs. These were broken between the lichen thalli to give similar replicates. Unlike the previous bark-disc technique this involved no cutting of the thallus and no necessity to distinguish between replicates with or without bark.

2. Construction of boards. The smaller type of boards were made up as in Fig. 4.7. The five lichen replicates were fixed in a random arrangement. The adhesive was applied to the twig, therefore ensuring minimal contact with the lichen.

3. Selection of sites. The final number of sites selected was 36 (see map and list in Fig. 5.1 and Table 5.1 respectively).

4. Positioning of boards on site. This followed the same procedure as in Survey 1. Boards were tied with plastic-coated wire to permanent features on site; they were at a height of 1.5 metres above ground and facing due North.

Fig. 5.1 Lichen Board Survey 2: location of sampling sites.

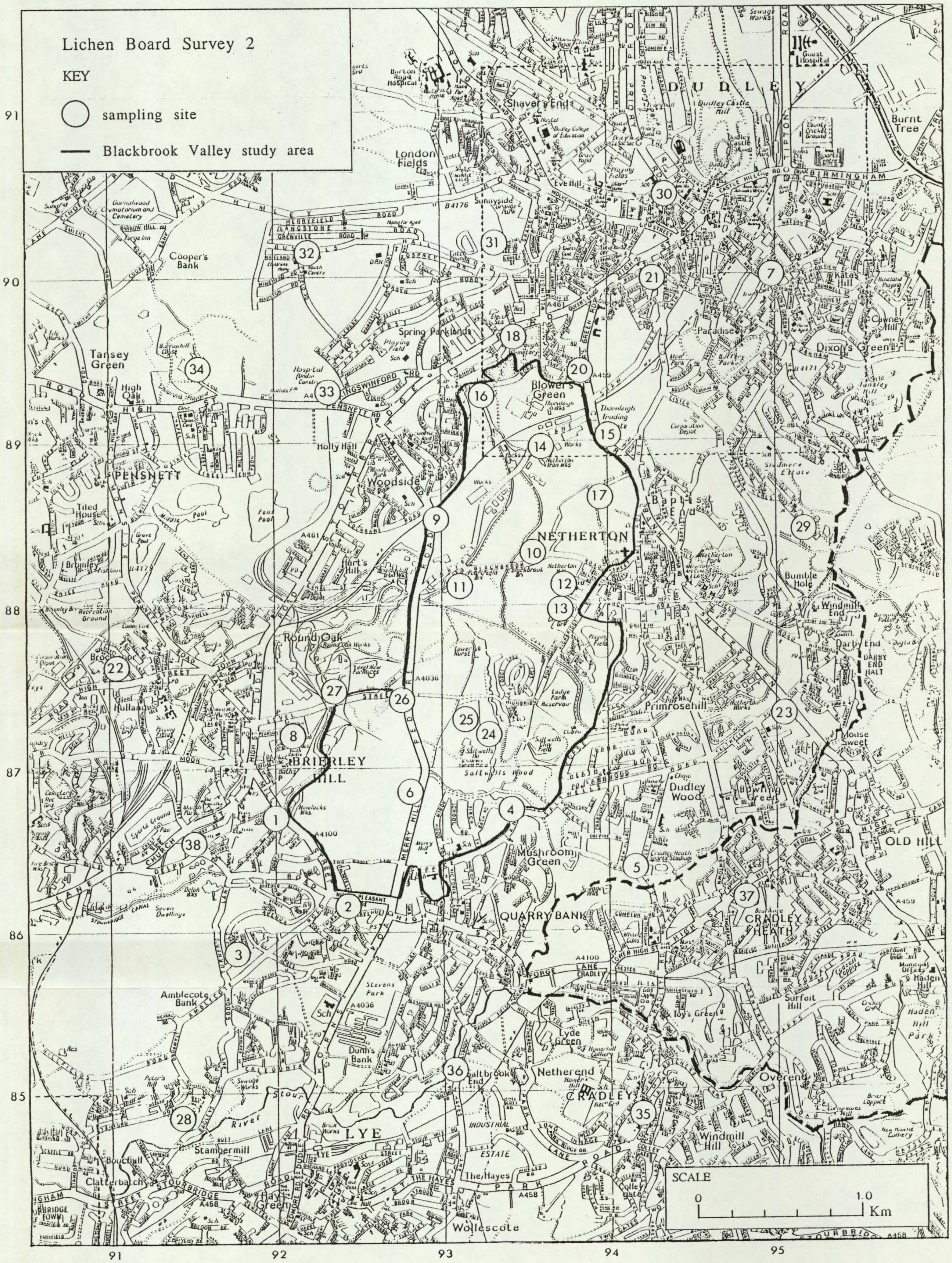


Table 5.1 Lichen Board Survey 2 - List of sampling sites

Site Location		Address	Map Ref
1.	Brierley Hill CP School	Mill Street	920 867
2.	Mount Pleasant Primary School	Mount Pleasant	925 862
3.	private house	Goldthorne Walk	917 859
4.	private house	56 Bath Road	934 867
5.	Methodist Church	Quarry Road	943 864
6.	Robin Hood Inn	Pedmore Road	928 869
7.	clinic	Dixon Green Road	949 900
8.	Olympia Testing Co Ltd	Level Street	922 872
9.	R.W. Priest Ltd	Pedmore Road	929 884
10.	field	Blackbrook Road	935 883
11.	Roof Units Ltd	Blackbrook Road	931 881
12.	Saint Andrews Parish Church	Church Road, Netherton	937 881
13.	school	Highbridge Road	937 880
14.	Lloyds Steel Works	Peartree Lane	935 889
15.	Herman Smith Ltd	Cinder Bank	940 890
16.	private house	32 Clee Road	932 893
17.	wasteground	Hall Lane	940 887
18.	Dudley Cemetery	Stourbridge Road	934 896
19.	Aston University	Birmingham 4	077 875
20.	private house	74 Blowers Green Road	939 894
21.	Home for the Aged	Abberley Street	942 900
22.	private house	School Road	910 876
23.	Saltwells Co Infant School	Saltwells Road	950 873
24.	woodland	Saltwells Wood LNR	932 873
25.	woodland	Saltwells Wood LNR	931 873
26.	Midland Oak Steel Training	Level Street	928 874
27.	canal bank	Level Street	923 875
28.	private house	33 Barn Owl Walk	914 848
29.	Council Flats	87-89 Saint Georges Road	952 884
30.	Dudley Council House	Ednam Road	943 905
31.	public land	off Fulbrook Road	933 902
32.	Rosewood School	Overfield Road	922 901
33.	Russell Hall Hospital	Pensnett Road	923 893
34.	vicarage	Vicarage Lane	915 894
35.	private house	13 Colley Lane	942 848
36.	Saltbrook End Public House	Saltbrook Road	930 851
37.	Saint Lukes Vicarage	Upper High Street, Cradley	948 862
38.	Baptist Church	South Street, Brierley Hill	915 865
39.	substituted for site 6		
40.	Aston University	Birmingham 4	077 875
41.	Aston University	Birmingham 4	077 875
42.	Aston University	Birmingham 4	077 875

* O.S. Map Sheet 139 (Section SO) 1:50000 Landranger Series

5. <u>Monitoring of exposure boards.</u> The basic procedure and monitoring intervals in Survey 1 had proved satisfactory but the need for improved picture quality and the smaller board design proposed for Survey 2 meant that more close-up photographs of the boards were required. However, as described in section 4.3.3 this had to be achieved without physically decreasing the focussing distance, which would restrict the use of the available flash unit. The following modifications proved suitable for this purpose:

a) camera was fitted with a longer focal length lens (135 mm) plus a close-up lens (+1 diopter)

b) focussing distance was increased to one metre

The boards were sprayed with distilled water prior to photographing. Lichens respond very quickly to changes in humidity of the air. The purpose of spraying was to ensure that the lichens were fully expanded, and therefore always in the same condition, for photographing.

6. <u>Controls.</u> The number and type of controls was greatly increased as recommended. Firstly, two exposure boards were erected at the Shropshire site as "clean-air" controls; three independent patches of lichen were located at the same site to test the method. At Aston four boards were used to test the effect of wetting. Finally, at four of the Blackbrook Valley sites and at Aston, old style boards were placed alongside the new boards to enable comparison of results from the two surveys.

7. <u>Assessment of exposure boards.</u> The procedure adopted for assessing the photographs was essentially as in Survey 1, but scoring was based on the German classification system detailed in section 4.5.2. The

standard score sheets were modified to take account of the smaller number of replicates and included a diagram of the board to enable the arrangement of replicates to be recorded for identification purposes. An example of the score sheet used is in Appendix D.

5.2.0 RESULTS

5.2.1 Control boards

There were four types of control boards, namely

Clean-air controls

Method controls

Aston controls

Board design controls

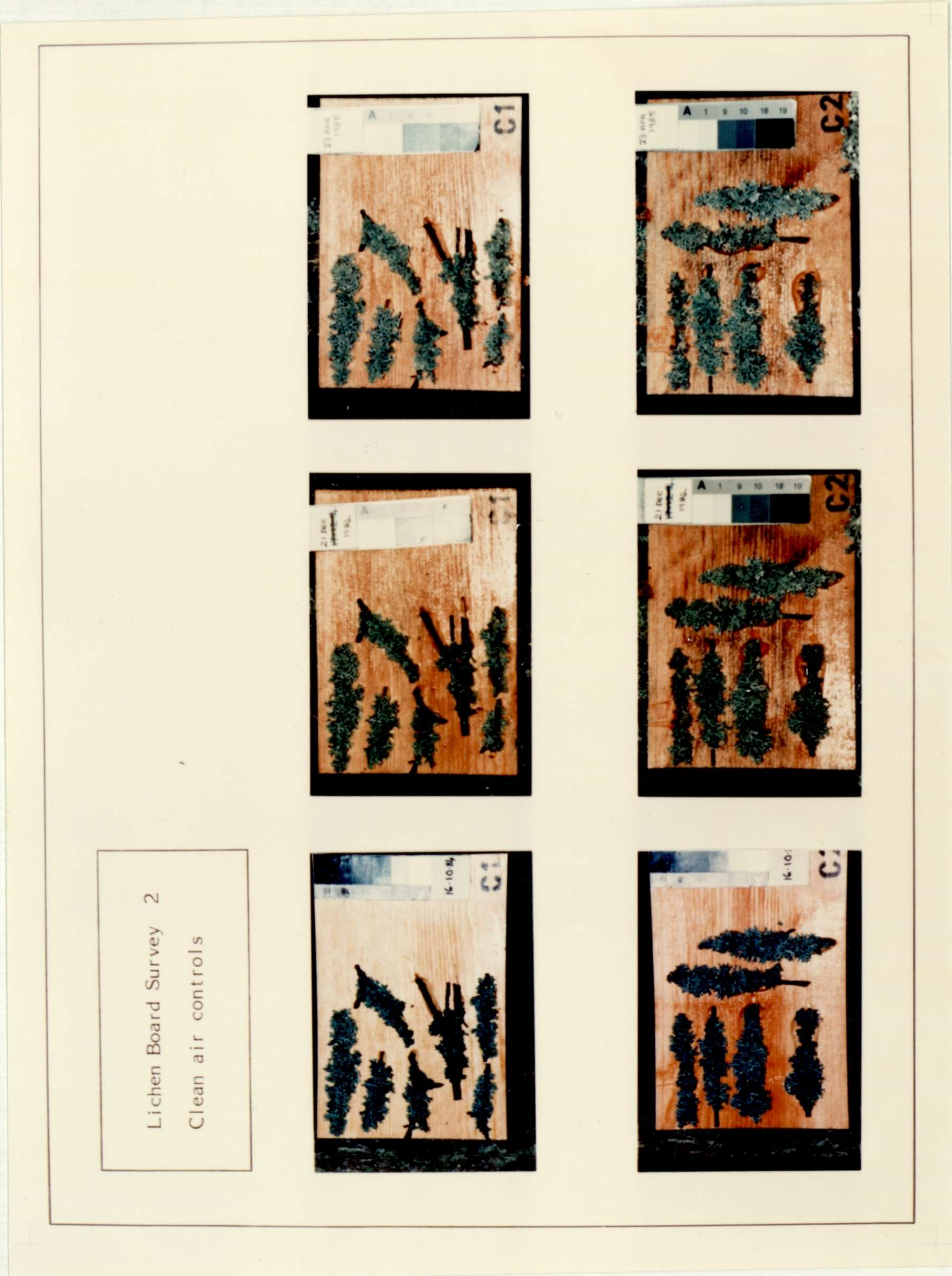
1. Clean-air control. Fig. 5.2 shows the photographic record of the two clean-air control boards. The scores obtained are summarised in Table 5.2 (full data in Appendix D).

Table 5.2 Clean-air control boards - mean scores (%green) with time

Week	C1	C2	all
0	96.88 (5)	96.88 (5)	96.88 (10)
9	96.88 (5)	93.75 (5)	95.31 (10)
20	96.88 (5)	88.54 (5)	92.71 (10)
26	95.31 (5)	88.54 (5)	91.93 (10)

Note figures in brackets indicate number of replicates
first 5 replicates only on C1 and C2 were used (see Fig. 5.2)

Fig. 5.2 Lichen Board Survey 2: photographic record of clean air control boards (C1 and C2) at Shropshire site. Dates shown indicate period of exposure as follows: 16/10/84 (Week 0), 21/12/84 (Week 9-10), 23/4/85 (Week 27).



Both the control boards showed a decrease in % green over the period of the survey. The combined mean score above gives a final percentage green which is similar to the "cleanest" boards in the Blackbrook Valley. While the percentage damage was not as high as shown by the majority of boards in the Blackbrook Valley it was greater than expected for the control site. However, there was evidence that the levels of lichen damage in both control boards were artificially high; the colour changes were brown and, on careful examination, appeared to be due to damping-off or some other kind of fungal infection rather than air pollution. A number of factors supported this. Firstly, there was no evidence of air pollution effects on any of the lichens growing in the area. Secondly, none of the method controls at the same site showed any signs of air pollution damage or brown colour. Thirdly, there seemed to be an association between brown colour and percentage lost, which may have contributed to the decrease in living material (see Table 5.3).

Analysis of variance carried out on all Blackbrook Valley data showed no significant difference in percentage green between replicates with (up to 50%) or without lost material. This suggests that the damage to lichen replicates resulting from air pollution was independent of, rather than a cause or effect of, lost material. The control boards constitute only a relatively small sample. However, the figures do suggest a link between brown colour and percentage lost. This would support the idea that the control boards were not showing the effects of air pollution.

Table 5.3 Clean-air control boards - further analysis of final %green scores

%Green	C1	C2	all
all reps	95.31 (6)	88.54 (6)	91.93 (12)
reps[1]	96.88 (5)	96.88 (2)	96.88 (7)
reps[2]	96.88 (5)	90.62 (3)	95.70 (8)
reps[3]	87.50 (1)	83.33 (3)	84.40 (4)

Notes [1] excluding all replicates with brown colour
[2] excluding all replicates with %lost greater than 0
[3] excluding all replicates with %lost = 0
figures in brackets indicate number of replicates

<u>Method control.</u> Examination of the control patches at the time of monitoring, and subsequent assessment of the photographs, showed that there was no change in the condition of the lichens over the period of the survey. A further visit to the Shropshire site in December 1985 confirmed that the control patches were still unchanged after more than one year of exposure. It can be concluded that the method of removing the lichen-bark disc, use of adhesive etc. had no noticeable effect on the lichen. It further confirms the observations of Schönbeck with respect to the condition of the lichen transplants (see page 90).

<u>Aston control.</u> According to Farrar:

> "it is now well established that the rate of many physiological processes in lichens is closely tied to the water content of the thallus, most metabolic activity being suspended when the thallus is dry."

In the first survey, as referred to in section 4.3.3, there was a period of dry weather during which there appeared to be a suspension of damage effects to the lichens. The control boards at Aston were intended to test whether wetting/drying had any effect on the level of air pollution damage in *H.physodes*. Two boards were exposed to the outside air on the roof of the Main Building at Aston University; one subject to normal wetting/drying by the prevailing weather conditions, the other being given additional wetting by being sprayed periodically with distilled water. Duplicates of these boards, one sprayed and one unsprayed, were placed in a glasshouse adjacent to the first treatments. These were to provide some measure of the level of air pollution damage to lichens receiving only artificial wetting. The results are summarised in Table 5.4.

Table 5.4 Aston control boards - final %green scores.

Treatment	sprayed	unsprayed*
inside	90.63 (5)	93.13 (5)
outside	82.50 (5)	88.75 (5)
all	86.56 (10)	90.94 (10)

Note * except for the purpose of photographing
( ) figures in brackets indicate number of lichen replicates

The results show that sprayed boards had a lower final percentage green score than those which were unsprayed. The difference between treatments was not very marked, possibly because the control experiment was not continued long enough (20 weeks). However it supports the idea that the results of the first survey were affected by lack of rain.

Board design control. The purpose of this control was to determine whether the results obtained from the two styles of board were the same or not, and so establish a basis for comparison of the first and second survey results. In comparing old and new boards it was necessary to take into account the different methods of scoring used. The two styles of board at each of the sites were therefore scored by using both the percentage (Survey 1) and German (Survey 2) scoring methods. The results are summarised in Table 5.5.

Table 5.5 Board design controls - final mean %green scores, with standard deviations indicated.

	Old board design (n=10)				New board design (n=5)			
Site no.	score[1] (a)	score[2] (b)	mean (c)		score[1] (d)	score[2] (e)	mean (f)	
5	76.3	71.9	74.1	(4)	83.8	88.3	86.1	(4)
	17.0	17.7			22.5	17.2		
8	66.7	66.7	66.7	(9)	53.0	57.5	55.3	(5)
	13.5	15.3			9.7	6.9		
11	94.8	95.0	94.9	(10)	80.0	84.4	82.2	(5)
	4.5	4.0			11.2	9.4		
24	83.8	83.9	83.9	(6)	93.5	93.1	93.3	(5)
	16.7	16.9			3.4	5.1		
43[3]	83.0	83.4	83.2	(10)	86.0	88.8	87.4	(5)
	10.1	9.8			7.4	9.0		

Notes
1 score estimated to nearest 5%
2 score estimated by German classification system
3 old style board matching with new style board 40 at Aston
( ) figures in brackets indicate number of replicates

Two points can be concluded from these results. The two scoring methods gave consistent scores for each board. However, the scores obtained for the two styles of board showed marked differences. Further analysis of these differences in scores is shown in Table 5.6.

Table 5.6 Differences in scoring methods of board design controls - further analysis.

Site no.	Old board design[1]	New board design[2]	mean score[3]
5	4.4	4.5	12.0
8	0.0	4.5	11.4
11	0.2	4.4	12.7
24	0.1	0.4	9.4
43	0.4	2.8	4.2
mean	1.02	3.32	9.94

Notes [1] columns (a) and (b) in Table 5.5
[2] columns (d) and (e) in Table 5.5
[3] columns (c) and (f) in Table 5.5

Reasons for these differences were considered.

1. Replication. In the case of boards 5 and 24 above, losses (greater than 50%) of lichen material reduced the number of replicates which could be included in the calculation. This may have contributed to the large difference between scores of the old and new type of boards. However this idea can probably be discounted because similar differences were also found for the other boards.

2. Lichen thallus. The two styles of board used slightly different types of material. Specifically the smaller board design did not involve cutting and pre-shaping of bark-discs.

3. Photographs. It seems unlikely that, in the same exposure conditions, there would be actual differences in the levels of lichen damage in the two styles of board. It is more probable that the differences in scores reflect the difficulties and errors associated with level of detail observable in the photographs of the two types of boards. It might be possible to apply a scaling factor to relate the first and second sets of results; otherwise there is limited scope for comparing absolute scores for sites in Survey 1 and Survey 2.

5.2.2 Blackbrook Valley sites

This section describes the findings of the second lichen board survey in relation to the Blackbrook Valley sites. Two aspects are considered:

(1) The progress of lichen death.

(2) The difference between sites.

The full data for the boards are in Appendix D.

Progress of lichen death. The survey took place over a period of 26 weeks. In this time the progress of lichen death followed a pattern similar to that in the first survey, with three identifiable periods of change. The period of main change for boards was between week 12 and week 18. At the end of this time %green scores for the different sites ranged from 6.9% to 95.0% (mean 68.6%), as shown in Fig. 5.3. The complete photographic records of three boards with different final scores are shown in Figs. 5.4 to 5.6. The scores of all the boards are summarised in Table 5.11.

The survey gave a very large amount of data. Furthermore, even for a single monitoring period (see Fig 5.3), there was a very wide range of values among the different boards. The first stage in assessing the results was to use analysis of variance to try to partition the variation in the data. There were three effects to be considered: time, replicates and boards. The variation of the board results (i.e. decline in % green) with time was distinct, as can be seen from the graphs. However it was not possible to assess the significance of this effect using analysis of variance, because the data for different time periods were based on repeated observations of the same lichen replicates, and hence were not independent. Analysis of variance in relation to replicates and boards was therefore carried out separately for each time period. The analysis confirmed that the amount of

Fig 5.3 Lichen Board Survey 2: graph showing range of lichen damage of different boards with time.

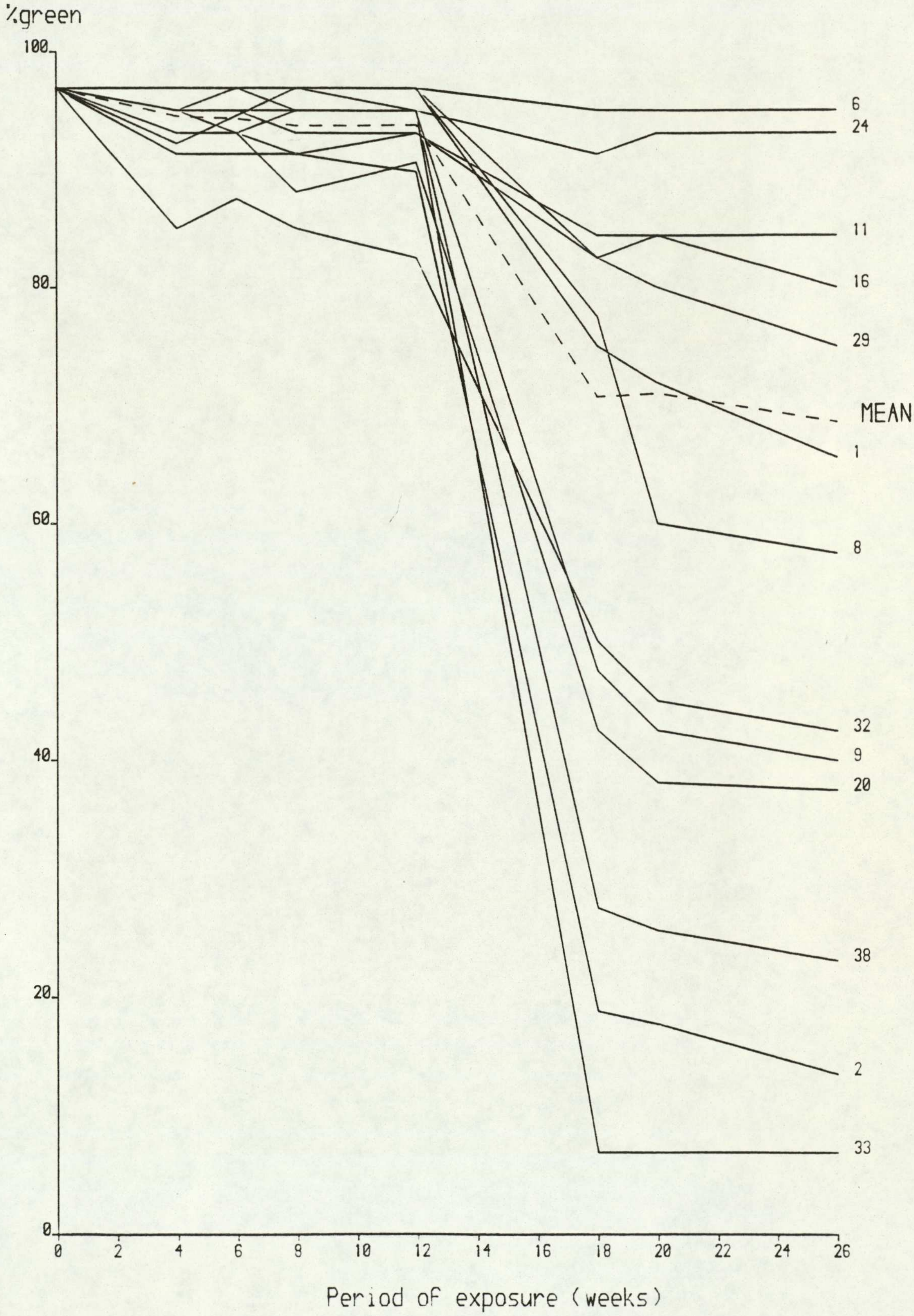


Fig. 5.4 Lichen Board Survey 2: photographic record of lichen board at site 2 (final score 13.54% green). Dates shown indicate period of exposure as follows: 22/10/84 (Week 0), 19/11/84 (Week 4), 3/12/84 (Week 6), 17/12/84 (Week 8), 14/1/85 (Week 12), 25/2/85 (Week 18), 11/3/85 (Week 20), 22/4/85 (Week 26).

Fig. 5.5 Lichen Board Survey 2: photographic record of lichen board at site 8 (final score 57.50% green). Dates shown indicate period of exposure as follows: 22/10/84 (Week 0), 19/11/84 (Week 4), 3/12/84 (Week 6), 17/12/84 (Week 8), 14/1/85 (Week 12), 25/2/85 (Week 18), 11/3/85 (Week 20), 22/4/85 (Week 26).

Fig. 5.6 Lichen Board Survey 2: photographic record of lichen board at site 11 (final score 84.38% green). Dates shown indicate period of exposure as follows: 22/10/84 (Week 0), 19/11/84 (Week 4), 3/12/84 (Week 6), 17/12/84 (Week 8), 14/1/85 (Week 12), 25/2/85 (Week 18), 11/3/85 (Week 20), 22/4/85 (Week 26).

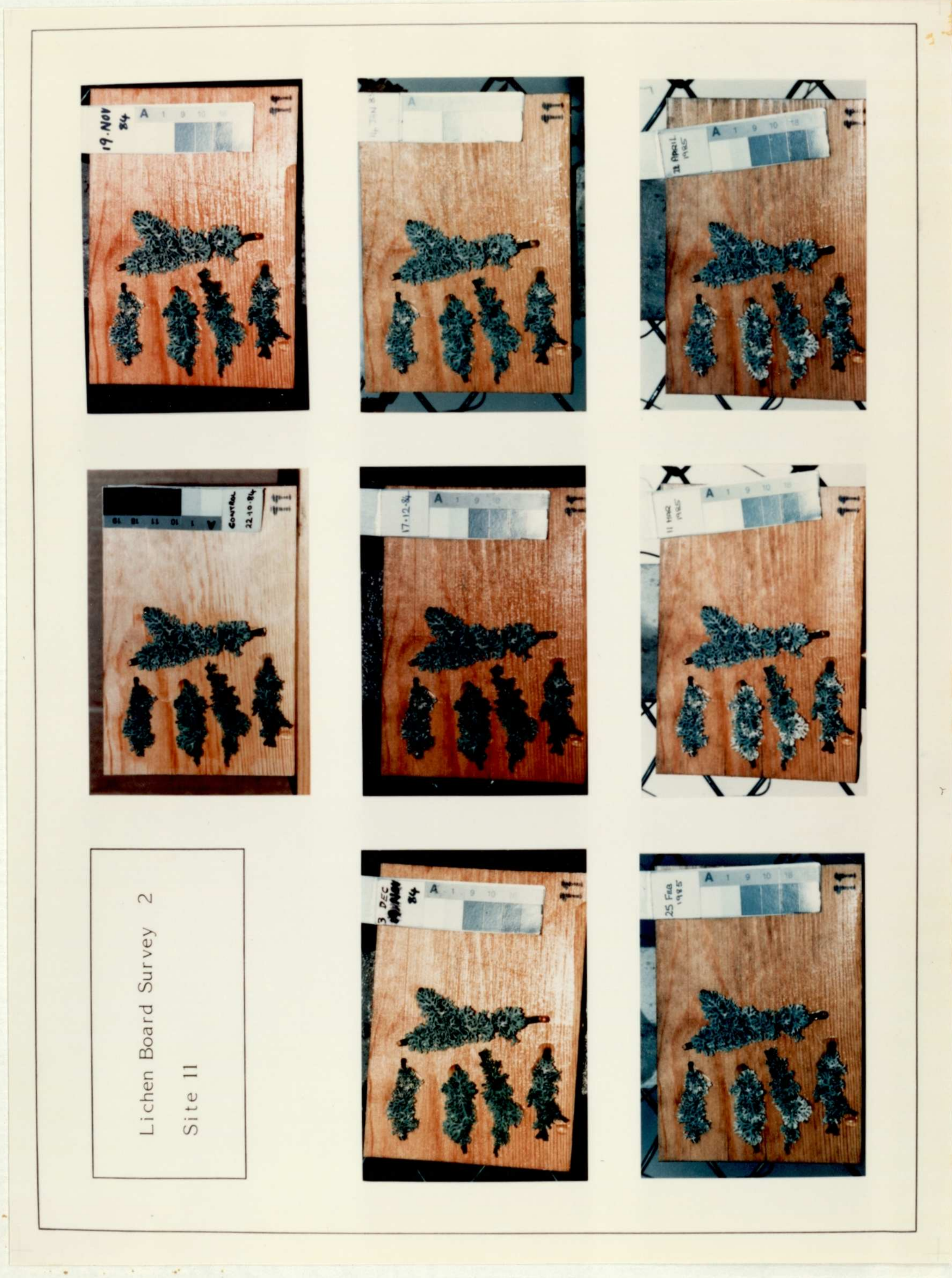
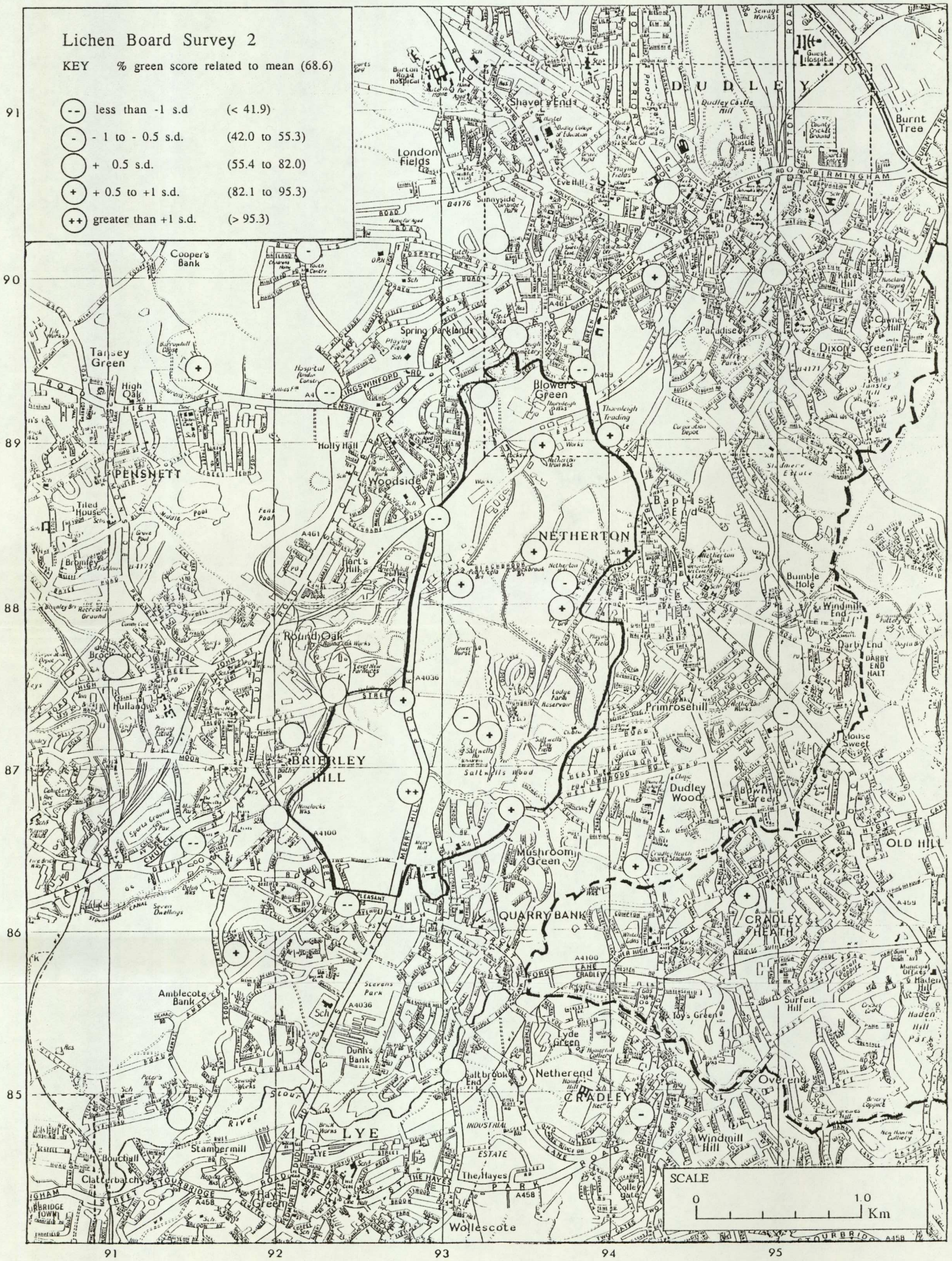


Fig. 5.7 Lichen Board Survey 2: final % green scores grouped in relation to the mean.



variation in the data which could be attributed to boards (sites) was highly significant ($p<0.001$) - see Table 5.9. Variation in the data due to differences between replicates was not significant.

Differences between sites. Table 5.11 shows the numerical distribution of results. To establish whether there was any pattern in these results it was necessary to look at the geographical distribution of the data. Fig. 5.7 shows the results grouped according to the degree of pollution effect measured. This was assessed relative to the mean value. These groupings show that most of the "average" sites, i.e. those with scores within 0.5 s.d. of the mean value, lay outside the main Blackbrook Valley survey area. The majority of sites inside the Blackbrook Valley area were "less polluted" than average. The site with the least lichen damage was site 6 (Robin Hood Inn, Pedmore Road).

Fig. 5.7 shows no immediately obvious pattern in the geographical distribution of results. Statistical analysis (linear regression) was therefore conducted to look more carefully at the results with respect to particular factors at each site. The following factors were considered:

a) Map reference - relative position north and east.
b) Height above sea level.
c) Approximate distance to nearest source of air pollution. Three source categories were considered:
   distance 1 - nearest domestic housing (any direction)
   distance 2 - nearest industrial area (any direction)
   distance 3 - nearest industrial area (in SW direction)

Factors in a) and c) above were aimed at taking into account the influence of the prevailing wind on the distribution of air pollution effects. Linear regression analysis was carried out on board scores (%green) against each of the above factors. Percentage green was also regressed against selected pairs of factors in combination, e.g. map reference north and east. No significant regressions were found for any of the comparisons made. The data for these factors are in Appendix D.

5.2.3 Comparison of Survey 1 and Survey 2

The purpose of this section is to assess whether there were any similarities or dissimilarities in the results of the two surveys, and to assess what conclusions, if any, can be drawn from these. As in the previous section there are two main aspects to be considered: a) the general progress of lichen damage and b) the differences between sites.

Progress of lichen damage. From the summarised data for all boards (see Table 5.7 and Fig 5.8 overleaf) it can be seen that the mean progress of lichen damage with time was similar for both surveys. For both surveys, analysis of variance indicated that the only significant source of variation in the data was due to differences between sites.

Table 5.7 Survey 1 and Survey 2 - progress of lichen damage with time (all boards)

Survey 1

Week	0	3	9	13	15	17	19	25
mean	97.0	93.1	90.1	86.6	79.5	76.3	82.5	69.1
s.d.	5.5	7.2	8.5	9.4	12.1	12.4	10.8	15.9
n	260	260	259	257	256	246	256	244

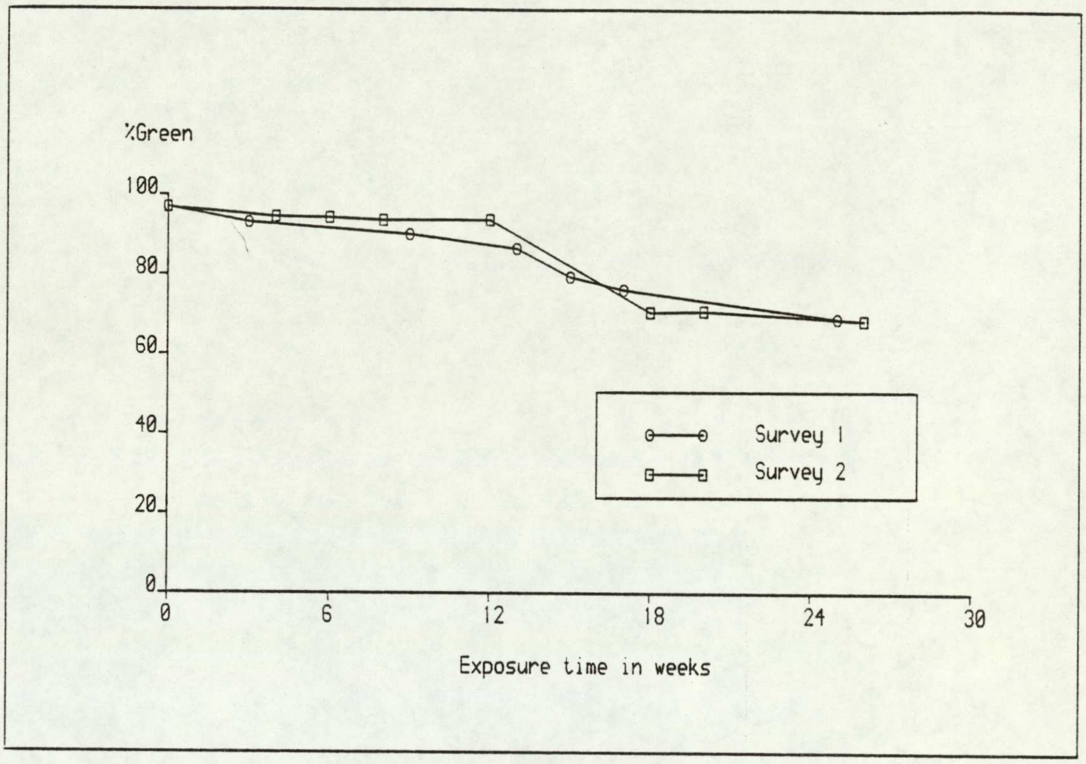
number of sites = 26

Survey 2

Week	0	4	6	8	12	18	20	26
mean	96.9	94.5	94.3	93.7	93.8	70.7	71.0	68.6
s.d.	0.1	4.6	7.5	8.2	8.2	25.7	25.1	26.7
n	180	179	179	178	174	156	159	143

number of sites = 36

Fig. 5.8 Survey 1 and Survey 2: graph plots of lichen damage with time (mean all boards).



Differences between sites. In this respect two sets of data are of interest, firstly the rate of change (gradient) of % green for the different boards and secondly, the final % green scores.

The rate of change of % green was determined by linear regression of the data for each board. For all boards in Surveys 1 and 2 the regression lines were found to be significant, indicating that all of the boards were affected as a result of exposure to conditions in the Blackbrook Valley. To compare the gradients for respective sites in the two surveys a regression and correlation test was carried out (Appendix D). Correlation between Survey 1 and Survey 2 data for some sites was high (>0.8) but there was a wide range of variation among the sites. Mean correlation for all sites was 0.63. The final % green scores are shown in Tables 5.10 and 5.11.

The means for the two surveys were more or less the same (about 69% green). The range of final scores indicated some important differences. For Survey 1 the median value was more or less equal to the mean value at 69.4%. There was a much greater spread of values for Survey 2 with the median value between 79.2 and 80.0%, indicating a greater proportion of "cleaner" sites. This result is the same even if new sites (i.e. those in Survey 2 not present in the original survey) are discounted.

In the above results some sites were more polluted than the worst sites in Survey 1, but some were likewise cleaner than the cleanest sites in Survey 1. Overall there appeared to be a shift in damage levels with a greater proportion of sites at the cleaner end of the scale. The difference can be seen clearly in the histogram in Fig. 5.9.

Fig. 5.9 Histogram to compare distribution of final scores in Survey 1 and Survey 2.

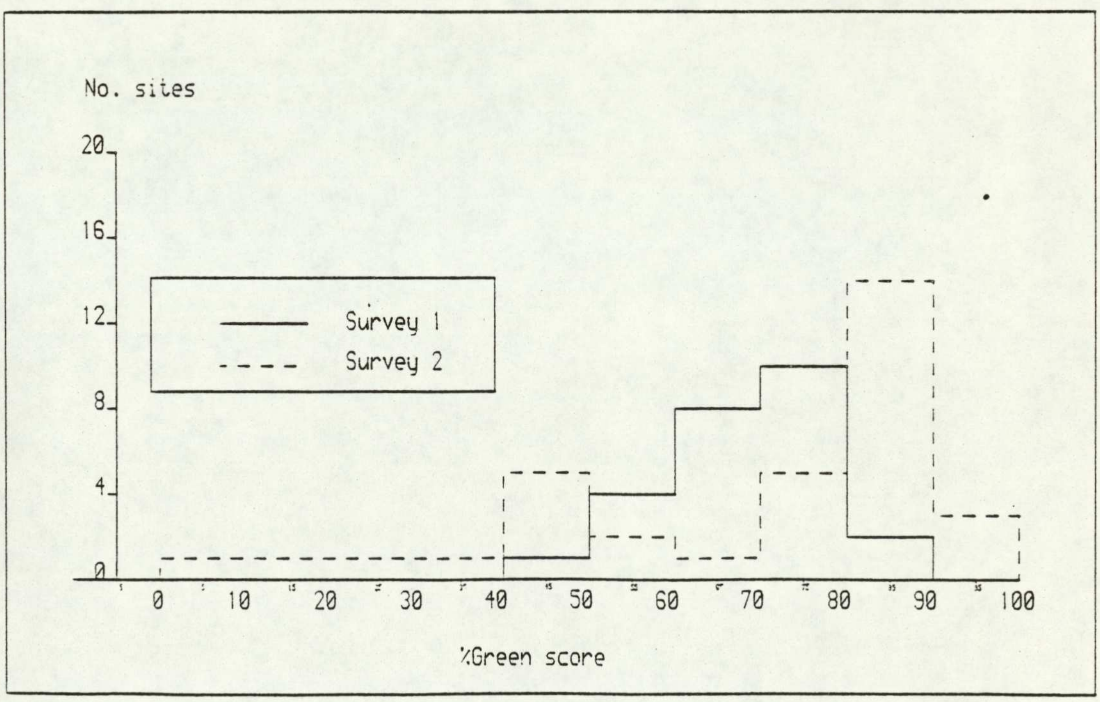


Table 5.8 Lichen board Survey 1 - analysis of variance among boards, calculated for separate weeks.

Week	F[1]	sig[2]	L.S.D.[3]	data excluded[4]
0	2.65	***	4.6	
3	4.40	***	5.5	
9	4.02	***	6.6	
13	3.86	***	7.4	
15	5.30	***	9.0	
17	4.26	***	9.6	
19	4.65	***	8.4	
25	5.71	***	12.1	1

Notes [1] mean square (boards)   error mean square (E.M.S.)
[2] at probability level p=0.001 $F_{(d.f.\ 24,\ )} = 2.13$
[3] Least Significant Difference = 1.96 x ((2 E.M.S.) ÷ 10)
[4] excludes boards with incomplete data

Table 5.9 Lichen board Survey 2 - analysis of variance among boards, calculated for separate weeks.

Week	F[1]	sig[2]	L.S.D.[3]	data excluded[4]
0		n.s.d.	-	
4	2.97	***	3.9	
6	1.79	**	7.0	
8	1.68	*	7.7	
12	1.27	n.s.d.	10.3	
18	15.24	***	17.3	7,26,27
20	12.50	***	15.9	7,27,35
26	9.87	***	18.2	7,10,27,35

Notes [1] mean square (boards)   error mean square (E.M.S.)
[2] at probability level p=0.001 $F_{(d.f.\ 30,120)} = 2.26$
[3] Least Significant Difference = 1.96 x ((2 E.M.S.) ÷ 10)
[4] excludes boards with incomplete data

Table 5.10 Lichen board Survey 1 - final scores ranked in order of increasing %green

Board	%green	notes
5	44.0	
19	52.0	
8	54.0	.... 53.2[1]
16	57.0	
28	59.5	.... 61.2[2]
2	64.0	
24	65.0	
25	65.0	
12	66.1	
18	67.0	
4	67.5	
9	69.0	.... Mean 69.1
15	69.5	.... Median 69.5
14	70.0	
13	70.6	
10	73.0	
7	73.3	
11	75.6	
26	76.5	.... 77.2[3]
3	78.5	
21	78.5	
23	79.0	
20	79.5	.... 85.0[4]
6	86.3	
27	87.8	

Notes
[1] mean - 1 s.d
[2] mean - 0.5 s.d.
[3] mean + 1 s.d.
[4] mean + 0.5 s.d.
standard deviation (s.d.) = 15.9%

Table 5.11 Lichen board Survey 2 - final scores ranked in order of increasing %green

Board	%green	notes
33	6.9	
2	13.5	
38	23.1	
20	37.5	
9	40.0	.... 41.9[2]
32	42.5	
12	43.8	
35	44.5 [1]	
23	45.0	
25	52.0	.... 55.3[3]
8	57.5	
1	65.6	.... Mean 68.6
28	70.0	
22	70.0	
29	75.0	
31	77.5	
18	79.2	.... Median 79.6
16	80.0	
30	81.3	
36	81.3	.... 82.0[4]
13	83.3	
11	84.4	
10	84.5 [1]	
14	85.0	
26	85.0	
37	85.0	
3	86.9	
21	86.9	
34	86.9	
5	88.3	
15	89.4	
4	91.3	
24	93.1	
6	95.0	.... 95.3[5]

Notes
[1] estimated value (based on regression line)
[2] mean - 1 s.d.
[3] mean - 0.5 s.d.
[4] mean + 1 s.d.
[5] mean + 0.5 s.d.
standard deviation (s.d.) = 26.7%

5.3.0 DISCUSSION AND ANALYSIS OF RESULTS

The results of the survey are analysed in relation to the objectives outlined in section 5.0.0. The following aspects are considered:

1. Effectiveness of the improvements to the method.
2. Results of control boards, particularly in relation to the first survey.
3. Results of the Blackbrook Valley boards.

5.3.1 Improvements to the method

The lichen board technique offered a relatively simple means of obtaining data on air pollution levels in the Blackbrook Valley. However, the first survey, carried out in 1983/4, had highlighted a number of practical problems. Recommendations, intended to resolve these difficulties, were made and were implemented in the second survey. The results of these improvements are now discussed. There are two main aspects: the collection of data and the assessment of the photographs.

1. Collection of data. In comparison with Survey 1 the preparation and setting up of the second survey was greatly simplified, and consequently many of the procedures were speeded up. Collection of the lichen material was more straightforward and, because no bark cutting was involved, less damage to the lichens resulted. Once the lichen had been collected, time for preparation of the boards was about one third to one half that taken for the first survey. The new design of board was smaller and therefore easier to position on site, as well as being less conspicuous than the previous design. Photographing time for each board was the same as before.

2. Assessment of photographs. Using the new board design and modifications to the photographic procedure, the image size of boards on the photographs was greatly improved. Consequently, the process of scoring was easier, aided also by the simpler German scoring system. The time taken for scoring was approximately one to two minutes per board, as compared with five minutes per board in the first survey. To test the objectivity of the new scoring system a subset of the photographs was re-scored using a transparent matrix overlay to measure the proportions of green and non-green material. There was a significant difference in the scores obtained by the two methods (see Table D11 in Appendix D), but this was found to be within ±10%. This is discussed in greater detail in relation to the results.

5.3.2 Control boards

The controls were carried out to test a number of different effects. In particular it was necessary to obtain information not available in the first survey.

Clean-air control. The results of the clean-air control boards indicated that there was no air-pollution damage at the Shropshire site. Although a statistically significant decrease in amount of living material (% green) was measured, the damage was not consistent with the effects of air pollution.

Method control. This was designed to test for possible adverse effects of the bark-removal technique and use of Araldite on the lichen. No noticeable effect was observed in four independent discs removed and replaced *in situ* at the Shropshire control site, even after a period of 12 months.

Aston (Moisture) control. As expected, this control demonstrated a measurable difference in lichen damage in boards subjected to extra wetting. This agrees with the literature. It is an effect which must be borne in mind in interpretation of results.

Board design. Analysis of the board design controls showed that different scores were obtained from the old and new board designs at the same sites. However, when the same boards were scored by the two scoring systems the results were more or less the same. It was concluded that this difference was mainly the result of differences in data observable in photographs of the boards.

5.3.3 Blackbrook Valley sites

Progress of lichen damage. The results of the clean-air controls indicated that there was no air-pollution damage at the Shropshire site. In contrast, the characteristic green-to-white colour change of *Hypogymnia physodes* was observed at all the Blackbrook Valley sites. Linear regression analysis of Blackbrook Valley board results showed that these were all significantly affected by air pollution over the period of the survey. The main occurrence of damage symptoms was between 12 and 18 weeks. This was similar to the result obtained in Survey 1.

Differences between sites. The results showed a wide range of variation between different sites (Fig. 5.3). Results for different sites were compared to determine whether there was any pattern in the distribution of air pollution effects, in relation to factors which influence the dispersion of air pollution. No significant correlation was found between sites and factors such as map reference, height above sea level and distance from different air pollution sources.

Possible reasons for the absence of a pattern in the survey data were considered. There were two possibilities, either a) no pattern existed, or b) the survey did not detect any pattern in the differences between sites. One way to establish whether it was reasonable to expect a pattern in the data for the study area, would be to compare the lichen results with other sources of air concentration data. This comparison could not be made. The only available information of a similar type was for metal levels, obtained by mossbag survey (see Appendix C). Comparison of this data with lichen board results was inappropriate because the two bioindicator techniques measure different dispersion and collection mechanisms.

Reasons why the lichen board survey may not have detected any pattern are now considered.

1. <u>Indicator response.</u> One possibility is that the lichen responded randomly or inconsistently to the effects of air pollution. However, this is unlikely. Firstly there was no reason to suspect the reliability of the indicator. As described in section 4.2.0, the species has been verified as a suitable indicator in many previous studies. Secondly, is the question of standardisation of material. Variation in condition of the lichen thallus (e.g. age), or characteristics of the collection site (e.g. aspect, moisture) affects the performance or vigour of the indicator and hence its response to air pollution. Analysis of variance of the Blackbrook Valley survey data showed that there was no significant difference among replicates on each board. This suggests that variations in the lichen, if any, were not sufficient to cause measurable differences in the performance of replicates.

2. <u>Comparability of sites.</u> The procedure for positioning boards at sites was standardised with respect to height and orientation, as described by Schonbeck. However, there may have been been other factors of importance in the effects of air pollution which were either not considered or not measured. For example, the original Schönbeck method used standardised steel posts to position boards, whereas the present survey used existing features such as walls, fences or trees. It is difficult to assess the effect that differences in these on-site features may have had on the small-scale environmental conditions of the boards, and hence on the survey results.

Related to the above is the question of replication. The survey was undertaken with the intention of detecting differences in air pollution effects between sites on a local (macro) scale. By placing only one board at each site there was no way of checking for within-site (micro-scale) variation. The results obtained for the sites were in effect random samples of a probable range of conditions at each site. This may account for certain anomalies in the results. For example, in both Survey 1 and Survey 2, there were instances where pairs of sites close together gave surprisingly different results, e.g. sites 24 and 25 (Survey 1), site 12 and 13 (Survey 2). Replication of lichens on each board was not a control for this effect. To give adequate replication of site results, a minimum of three boards should be placed at each site, at 2 or 3 metre intervals.

3. <u>Lack of information.</u> A further difficulty with interpretation of the survey results is due to lack of additional information regarding a) the effects being monitored and b) the environmental conditions at the survey sites. These two aspects are related. Lichens and other biological monitors are integrating monitors. They give a cumulative or

total-effects measure of conditions throughout the survey period. Unless combined with detailed microscopic/physiological examination of the indicator material, the survey method does not enable the researcher to distinguish the effects of different pollutant species (e.g. SO_2, NO_2) or different degrees of air pollution effects (i.e. chronic and acute effects) within the observation period. Localised peaks of high pollution loads may affect individual sites, distorting the overall picture of site differences. Garden fires are one source of such localised effects, which may have affected some of the Blackbrook Valley sites. Further information on site conditions during the survey would be required to monitor such effects. The main types of additional data required are climatic data and measurements of air concentrations from conventional monitors.

a) <u>climatic data</u>

The most important climatic factors which need to be considered are wind speed and direction. The nearest area to the Blackbrook Valley, for which climatic data was available, was Edgbaston (University of Birmingham meteorological station).

In comparing damage levels with site factors, such as proximity to polluters, wind direction was obviously important. South West was assumed to be the most likely source of emissions. Climatic data for Edgbaston shows that one third of winds throughout the year come from WSW-SW-SSW (see Appendix E). However the impact of pollutants from other directions will be significant depending on the location of individual sites, and on different times of year. During Survey 2, for the period October to December 1984, 44% of winds were from the S-SSW-SW direction. In the following months of January to March 1985 this proportion was less than half (21.8%); the main wind direction in this period was from NE-ENE-E (27%).

To assess the relative importance of different wind directions on individual sites, analysis of data with respect to individual wind direction categories at each site would be required. Such analysis would require a number of other facilities, namely

1. A sophisticated model/programme to carry out the necessary calculations.
2. Relevant climatic data. Edgbaston data does not adequately represent conditions in the Blackbrook Valley.

In the second case, basic meteorological measurements for rainfall, wind speed and wind direction (as a minimum) would need to be measured directly in the study area, preferably by means of a permanent weather station.

b) <u>conventional monitors</u>

In order to obtain this type of information conventional monitors were required for at least a few sites in the Blackbrook Valley, in addition to the lichen boards. There were a number of reasons for this.

Firstly, the lichen board method used gives only a relative measure of air concentrations. There are limits to the information which can be assessed from general data and relative differences between sites. Eventually these differences need to be related to specific air pollution concentrations. The literature emphasises that biological monitors should be used <u>in conjunction</u> with conventional monitors[1], particularly if these are to be used in an air pollution monitoring programme. To quote Case:

> "Biomonitoring and physical/chemical monitoring complement each other by providing an evaluation of the physiological and ecological effects of accurately measured pollutants. Therefore both types of monitoring should be conducted simultaneously."(2)

Secondly, even where calibration scales or values have been developed for a particular pollutant-indicator species interaction, these cannot be reliably applied to new areas without checking/recalibration. One reason for this is the effect of genetic differences in lichens from one area to another. The total mix of environmental factors in each study area will also be different.

5.3.4 Comparison of Survey 1 and Survey 2 data.

Results in section 5.3.5 show that the general progress of lichen death was the same for both surveys. The mean final scores for all boards was also similar (69%). The periods during which the main lichen damage occurred were week 13 to 19 (Survey 1) and week 12 to 18 (Survey 2). This suggests that the overall conditions in the Valley may have been similar for the two survey periods. Overall comparison of matched sites shows very little correlation. However, the standard deviation of results for survey 2 was almost double that for Survey 1. When ranked data for matched sites are compared, there are similarities for some sites:

e.g. site 6 (highest %green at the final week in both surveys)

sites 3 and 21 (high %green)

sites 13, 10, 11, and 14 (clustered distribution in both surveys)

The above observations offer some evidence to support the idea that a pattern does exists in the survey data. However, there are a number of problems with comparisons of the two surveys.

1. Lichens show marked seasonal variation in physiological activities, and hence in characteristics such as algal cells/unit area, carbohydrate

or chlorophyll level as summarised by Farrar.[3] However, work by Richardson[4], for example, shows that such characteristics may show poor correspondence in successive years. Surveys 1 and 2, although conducted at similar times of year, may not be comparable for this reason.

2. Absolute data values for the two surveys cannot be reliably compared. This is discussed in pages 147-48.

5.4.0 CHAPTER SUMMARY

This section summarises the improvements to the method from the second lichen board survey, and outlines remaining problems with the survey technique.

5.4.1 Improvements to the method

The first survey revealed a number of practical difficulties with the method. The improvements to the method implemented in the second survey largely resolved these difficulties. The second survey methodology eliminated many of the sources of error in the data, due to variation in lichen discs, namely

a) presence/absence of bark (and related problems of sample collection),
b) the significance of brown colour changes, and
c) conspicuousness of boards and associated problems of vandalism and losses of boards and/or lichen.

Secondly, the smaller board design enabled more detailed photographs of boards to be obtained, overcoming some of the problems/difficulties of the scoring process.

Thirdly, the number of survey sites and controls was improved. The clean-air and method control boards confirmed that no adverse effects were caused to the lichen transplants by the procedures of the method/technique itself. This agrees with the observations of other workers in the literature.[5,6,7]

5.4.2 Remaining problems

The results of the lichen board surveys gave clear evidence of the presence of air pollution effects at all the sampling sites in and around the Blackbrook Valley study area. The final range of damage scores indicated considerable differences between sites within the study area. However no clear pattern was identified in these differences. From the results of the second survey, the principal reasons for this were suggested to be

a) inadequate replication of site results, and

b) lack of detailed information regarding site conditions.

The combination of these factors means that there is no way of confirming the accuracy or value (equivalent pollutant air-concentrations) of the site results. In particular, there was no suitable data available for comparison with the survey results to establish whether or not a pattern could be resonably expected. Some evidence for the existence of a pattern was shown by the general similarities between Survey 1 and Survey 2 results. Comparison of these results showed:

1) Progress of lichen death followed the same pattern, with the main onset of damage symptoms occurring at the same times i.e. between 13 and 17 weeks (Survey 1), and between 12 and 18 weeks (Survey 2).
2) The two surveys had the same final score i.e. approximately 69% green (mean all boards).

Detailed comparison of results for the two surveys showed very little correlation, although there were similarities for some sites. Lack of correspondence in the results of the two surveys is attributed, in part, to the problems of scoring photographs. The board design controls showed that the use of different scoring procedures had no effect on results obtained from the same board (photographs). However, the scores obtained from photographs of the two different board designs at the same site were not the same. It is suggested that differences in the level of detail observable in photographs of the two types of board are the reason for this. In particular, the small size of image in Survey 1 photographs made scores difficult to assess.

The above may also account for the different range of scores obtained in the two surveys. In Survey 2 there was an apparent shift in proportion of clean sites, compared with Survey 1. It is tempting to suggest that this reflects an improvement in environmental conditions in the second survey period. However, this is unlikely.
1) The sites were grouped for comparison by relating scores to the mean; however the standard deviation for Survey 2 was double that for Survey 1.
2) Although the number of apparently "cleaner" sites was increased, the number of "dirtier" sites also increased. The % green scores of the most polluted site was much less (6.8%) than for the dirtiest site in Survey 1 (44%).

The possibilities for comparing Survey 1 and Survey 2 results, particularly absolute values, are therefore limited.

Comparing matched sites for the two surveys reveals some interesting points. Site 5 in Survey 1 was the most polluted (44% green) but in Survey 2 was one of the "cleaner" sites (85%). It is difficult to believe that the difficulties of the photographic image and scoring could have lead to such a discrepancy if the environmental conditions were the same. It is more likely, in this case, that there were real differences in environmental conditions in the two surveys. This could indicate seasonal or local variation in conditions between the two surveys. Other site results could conceivably represent similar conditions in both surveys (highlighted in discussion section 5.3). Increased replication would demonstrate the reliability of results at individual sites (microtopographical variation). The chief area of interest to the NCC is Saltwells Wood LNR. It is interesting that this was not as badly affected as many other sites in the study area, although it is difficult to assess the meaning of such a comparison in terms of air pollution concentrations without further data.

CHAPTER 6

DISCUSSION AND CONCLUSIONS

CONTENTS:

6.0.0 OUTLINE

This thesis has described the selection and implementation of a method for obtaining information on air pollution in the Blackbrook Valley. Chapter 6 assesses the research in relation to the literature and objectives of the Blackbrook Valley Project. The discussion focusses on the results of the lichen board study, and associated methodology, and evaluates the practical and theoretical knowledge gained. Recommendations for the Nature Conservancy Council are presented.

6.1.0 INTRODUCTION

6.1.1 Research objectives

The objectives of the present IHD research must be viewed in the context of the Blackbrook Valley Project, of which they form part. Two aspects are of particular significance. Firstly, the Blackbrook Valley Project is a long term environmental monitoring programme. The present research has concentrated on establishing the baseline data for the air pollution aspect. Secondly, the NCC is primarily concerned with monitoring the effects of air pollution on the biological status of the valley. The presence of Saltwells Wood Local Nature Reserve (LNR) in the locality has provided a focus for the research, although the results have wider implications.

6.1.2 Research methodology

At the outset of the IHD project, detailed information on air pollutant concentrations was not available. The research has looked at ways of obtaining this information in order that work on pollution effects can be tackled.

Examination of the relevant literature (reported in Chapter 2) established that there were two approaches to obtaining data on air pollution concentrations, namely

a) directly: by measurement of ambient air

b) indirectly: by calculation

Both approaches were studied in the first year of the research.

The direct measurement of air pollution concentrations conventionally involves physical or chemical methods of sampling and analysis. Attention has been drawn to the problems of this approach. In particular, calibration of equipment and subsequent on-site maintenance/surveillance tend to be difficult and expensive. In the case of the Blackbrook Valley, cost was a significant limiting factor and an alternative approach was required. The use of biological indicators was seen as an inexpensive means of data collection for obtaining information on air pollution concentrations.

The indirect approach to obtaining air pollution concentration data, by calculation, requires information on emissions and sources. This highlights the importance of compiling detailed baseline data. Ways of obtaining this data for the Blackbrook Valley needed to be found. The compilation of an emission inventory was identified as the optimum method of obtaining information on pollution sources and emissions. In relation to this, dispersion modelling was seen as the means of linking information on sources (inventory data) and ambient concentrations, and to enable prediction of pollution levels for management or other purposes.

Work undertaken in the above aspects has been described in Chapter 2 (emission inventory and dispersion modelling) and Chapter 3 (use of biological indicators). The results of these preliminary research themes are now discussed.

6.2.0 PRELIMINARY RESEARCH RESULTS

6.2.1 Emission inventory and dispersion modelling.

The development of an emission inventory system provides a means of compiling data on air pollution sources. The baseline data of many of the modelling studies described in the literature are provided by an emission inventory. In theory, the same approach could be used to map/model the distribution of air pollution concentrations (and, ultimately, air pollution effects) in the Blackbrook Valley.

Examination of the emission inventory approach revealed a number of problems. The first problem is to identify and list the items in the inventory, in this case the location and nature of sources in the study area. Secondly, it is necessary to define the type of sources information required. As described in Chapter 2, the exact type of data and resolution required are dependent on the specific purpose(s) for which the inventory/models would be used. These need to be carefully defined beforehand by the organisations concerned.

The third problem in considering the emission inventory approach is to assess how the required information would be collected. The standard approach described in the literature is to divide sources into two categories, point and area sources. The criterion usually chosen for distinguishing these is the emission rate of the pollutant or pollutants of interest. This can be calculated on the basis of size and rating of the boiler or industrial plant concerned, or on the basis of the emission rate per unit of time (which may take into account the seasonal variations or peaks in pollutant load). Major industrial plants are generally treated as point sources, whereas smaller factories or industries, domestic and institutional premises are treated as area sources. The specific emission rates are selected according to the needs and resources of the users of the inventory. In part these will be dependent on the total numbers of emitters in the survey; it may be necessary to select the critical value to reduce the number of point sources to a "manageable" amount. According to Ball:

> "the lower it (the dividing line) is placed the greater is the number of point sources and the greater is the work involved in surveying them, but the precision of the inventory is improved."(1)

An emission inventory would be a convenient management tool to use in the Blackbrook Valley. However, the specific emission rates used as criteria for distinguishing point and area sources, as described in the literature, would not be appropriate. In the Blackbrook Valley the total number of sources is relatively small and, following the closure of Round Oak Steel Works, there are no major industrial emitters. The emissions from industrial sources in the Blackbrook Valley are mostly the result of process heating and likely to be of similar size. In considering the use of an emissions survey for the Blackbrook Valley, the decision needs to be made as to which emissions are of main interest: those from the largest emitters (which in general will be industrial plants), or the residual or background pollution levels (which will be mainly the result of emissions by area sources). Both approaches are probably required. Geographical location may be the best criterion for identifying the main groups of sources. Land Use Classification (LUC) data, census statistics and other local authority data may provide the necessary classification system to identify the different categories of sources.

Possible sources of information for the collection of the required inventory data were examined, as described in Chapter 2. In particular Dudley Council conducts an annual survey of the Enterprise Zone, including some details of air pollution emissions. However, it was concluded that this was not sufficiently detailed or complete for the purposes of the present research. The main difficulties were:

a) there were not enough categories of information to enable comparison of emissions from different industrial processes/plant, and cross checking of calculations with examples in the literature, and
b) the standard of completion of the survey forms was inconsistent, which meant that important information was often missing.

A detailed survey, of the type which would be required for emission inventory/predictive modelling, would not be possible without obtaining further information on air pollution sources and emissions, either from purpose-collected data or from conducting a questionnaire. As described in Appendix B, the posssibility of undertaking a purpose-designed questionnaire was explored and, for political reasons, was found to be unsuitable. Using generally available data, only a rapid survey would be possible, which would have limited use in a predictive/dispersion model.

The NCC and Dudley local authority are interested in the use of modelling. As described in Chapter 2, this provides the means of relating information on emissions/sources (obtained from a purpose-made inventory or from available data) and air concentrations. Two uses of such a model were previously identified as
a) ecological effects monitoring
b) environmental planning/management

Possible approaches to implementing these were examined. The source-oriented approach is the main method described in the literature. This uses known relationships between emissions and dispersion factors to predict air concentrations from data on sources. It therefore forms the ideal basis for a planning/management model. However, as previously described, the NCC is more interested in receptors of air pollutants than in sources. Therefore, in the long term, a more appropriate model for the NCC is a receptor-oriented approach. Targetted on Saltwells Wood LNR, this would provide a more direct means of assessing the relevant pollution contributions from different sources/areas. Receptor models described in the literature generally require higher quality data than source-oriented models; data which is not available in the Blackbrook Valley. A more feasible approach, providing a better option for the present needs, would be to identify a suitable source-oriented model, which could then be used "backwards" in *lieu* of the receptor models described in the literature.

The difficulty with all of the above approaches is that they rely on the availability of detailed information on emissions/sources, which was not immediately available for the Blackbrook Valley. In this situation, estimates are of limited value unless the degree of "estimation" can be quantified. In general the literature describes models which are designed for use in areas much larger than the Blackbrook Valley. They also use very detailed meteorological data to predict dispersion patterns.

The uses of an emission inventory and dispersion modelling are complementary approaches in an environmental monitoring programme, and there was little point in pursuing them separately. In view of the difficulties outlined above, these approaches were not developed further.

6.2.2 Biological indicator approach

The use of biological materials as indicators of air pollution, is well documented. It offered the possibility of an inexpensive way of obtaining data on pollution levels. In particular, the literature has shown that biological monitors can be applied where the use of conventional techniques is too expensive or impractical. As described in Chapter 3, the chief strength of biological monitors lies in their ability to measure data of direct relevance to the biological systems under study. Conventional monitors often do not measure the relevant pollutants and may require complex calibration or interpretation to render the measurements useful in biological terms. On the other hand, biological monitors may not necessarily be representative of all biological species or organisms. The most representative results will be achieved by using indicator species with known properties or the species of interest itself. Both of these uses assume that the main object of interest is the biological species. There were a number of difficulties in using observations of species from the study area, specifically

a) the small scale of the area,

b) associated lack of suitable natural vegetation stands for simple vegetation mapping, or sampling

c) lack of facilities/resources for sophisticated experiments

Transplants were identified as the best means of overcoming these problems. The particular advantages of transplants are:

1. Increased control of the biological material e.g. genetic composition, origin, age, etc. Natural vegetation may be unsuitable for monitoring pollution in the area of origin due to the evolution of genetic resistance.(2) Similarly, the natural vegetation may have an unknown history of previous exposure to the effects of air pollution, which would complicate the interpretation of any monitoring data derived from it. With transplants the period of exposure to the environmental conditions of the study area can be determined more readily.

2. Transplants overcome lack of suitable "resident" indicator species in the study area. In this respect the use of biological materials in the Blackbrook Valley would be in a mainly non-biological sense, as replacements for physical/chemical techniques. This approach to the use of biological monitors is supported by the literature.[3]

6.3.0 MAIN RESEARCH: LICHEN BOARD SURVEY STUDY

6.3.1 Assessment of the lichen board. technique

This section reviews the results of the lichen board study and assesses the value of the technique in relation to the air pollution research. The discussion is divided into two parts.

a) the implementation of the lichen board methodology

b) interpretation of the survey results in terms of the Blackbrook Valley

6.3.2 Lichen board methodology.

In practical terms the lichen board method was successful. The boards were relatively simple to prepare, and to set up/monitor in the study area. The main practical problems related to security of the boards. Incidences of vandalism led to losses of lichen material and, in some cases, whole boards. Careful site selection and positioning of boards in the grounds of private houses and attended areas, such as factories or schools, offered the best protection. In the second survey losses of boards were noticeably reduced. The smaller size of the new board design is likely to have contributed to this.

A major problem with the lichen board technique is scoring/photographic detail. Problems with scoring were found in both surveys and are discussed in detail sections 4.3.2 and 5.3.1. There were two aspects

a) detail observable in photographs

b) objectivity and reproducibility of the scoring process itself

The first aspect applied particularly to Survey 1. The image size of whole boards was found to be too small to enable scoring to be carried out easily. This problem was compounded by the the over-detailed scoring resolution chosen. This problem was overcome in the second survey as a result of the modified board design, which enabled larger images of the lichen damage to be seen in standard sized prints. The individual photographing of replicates remains the best option for users of the survey technique, where the progress of lichen damage is not of interest. The adoption of a simpler scoring system also improved the speed of scoring. The same image improvements could have been achieved by photographing the discs individually, as described in the original study by Schönbeck(4) on which this method is based. However, because of the large number of monitoring sessions involved this would have increased the photographing time and costs to an unacceptably high level.

The problem of objectivity and reproducibility of the scoring process can only be resolved by further investigation. The scores obtained in Survey 1 and 2 were found to be reproducible to within $\pm 10\%$. This was judged to be an acceptable level of variation. In contrast, scores obtained by a group of independent observers were even more variable than the sets of scores obtained by the author. This suggests that a highly routinised method for defining the scoring procedure may need to be developed to enable general use of the technique, and to enable cross comparison of results from different surveys.

Ultimately, the questions of accuracy and objectivity may not be too important. These factors are dependent on the aims of the survey. In particular, it is necessary to decide what resolution of information is required. This must be defined in specific terms, namely

- what kind of survey is required, e.g. "spot-checks" or year by year comparisons?
- how often the survey is to be repeated, if at all?
- what exactly is to be measured, e.g. progress of damage or final scores?

6.3.3 Lichen board results.

Two surveys were carried out, in the winter/spring period of 1983-84, and 1984-85. These have been discussed in detail in Chapters 4 and 5 respectively. Results showed that:

1. The test plant *Hypogymnia physodes* demonstrated characteristic air pollution damage when exposed in the Blackbrook Valley. No air-pollution damage was shown by the clean-air controls at the Shropshire site.

2. Linear regression analysis showed that all boards in the Blackbrook Valley were significantly affected by air pollution. The progress of lichen death (Survey 1 & 2) involved three identifiable periods of change. The main occurrence of damage symptoms was between 13 and 15 weeks (Surveyl) and 12 and 18 weeks (Survey 2).

3. At the end of the exposure period percentage green scores for the different sites ranged from 44.0 to 87.8 (Survey 1), and from 6.9 to 95.0 (Survey 2). Mean final scores were 69.1% and 68.6%, respectively. The wide range of damage levels among boards, indicated

that the lichens had been exposed to different levels of air pollution at different sites.

Analysis of variance confirmed that the amount of variation in the data which could be attributed to boards (sites) was highly significant ($p<0.001$) - see Tables 5.8 and 5.9. Variation in the data due to differences between replicates on individual boards was not significant.

4. Differences between sites were examined to determine whether there was any pattern in the results, in particular with respect to factors which are known to influence the dispersion of air pollution. No significant correlation was found between sites and factors such as map reference, height above sea level and distance from different air pollution sources. Reasons for the absence of a pattern were examined. The performance of the indicator was not considered to be a significant factor. Analysis of variance confirmed that there was no measurable difference among the board replicates. However, lack of replication of lichen boards at individual sites was identified as a possible cause of variation in results. To determine specific air pollution concentrations from the effects observed would require information on environmental conditions.

6.4.0 RECOMMENDATIONS

6.4.1 Practical considerations.

The method undertaken in this research provided a relatively simple, inexpensive means of obtaining data on relative air pollution concentrations.

In implementing the method particular attention should be paid to the following practical aspects.

1. Standardisation of collection procedures.

This is essential to eliminate unwanted variation in the test material. The method developed in this research provides an effective means of dispensing with the need for bark-discs. Unless a purpose-designed excision tool is employed to remove bark-discs, as described by Brodo[5] for example, there is a great risk of damage to the lichen. This introduces variation into the replicates and may predispose them to damage by air pollution. The use of twigs, as adopted here, is both less time-consuming and less destructive than the bark-disc technique. However, like the latter, it ensures that contact between the lichen thallus and the adhesive is minimised, a factor which according to Gilbert[6] and Rose[7] is essential to prevent damage to transplants. The control lichen replicates, replaced *in situ* at the collection site, confirmed that there was no adverse effect of the method on the transplants even after a period of 12 months.

2. Location and standardisation of sampling sites.

As with the collection of lichen material, standardisation of procedure for positioning of boards at sampling sites is important.

3. Scoring procedures/photographing boards.

Comparison of the results of Surveys 1 and 2 confirmed the value of maximising picture detail in photographs of lichens. Better results would be obtained by photographing replicates individually. In this case objective techniques such as light pens or tracing techniques would be appropriate to measure the differences between the control and final photographs.

It is also important to define a procedure for treatment of lost material. The criterion of ignoring replicates with greater than 50% losses, as adopted in the present research, proved satisfactory.

4. Geographical scale and spatial resolution.

These are factors which need to be carefully considered. The results of the Blackbrook Valley surveys suggest that there may be considerable differences in air pollution concentrations between sites as a result of localised variation in environmental conditions. The significance of this is twofold. Firstly, it points to the need to investigate more fully the sampling resolution of the method. Related to this is the question of what monitoring period is required to sample the environmental variation reproducibly. If the pattern of impact is very variable in the Blackbrook Valley, a high density of sampling points may be needed to identify it. The method may be more appropriate to large fairly homogeneous areas with less variation. Another aspect of the problem is the resolution of the survey method. If the background levels of air pollutants are high then identification of differences between individual sites will be difficult.

Secondly, it underlines the importance of deciding what sampling resolution is required for the survey. This is discussed further in relation to the problems of mapping concentrations.

5. Replication.

Adequate replication of boards at sites is essential. In the case of areas like the Blackbrook Valley it is probably better to choose a small number of "representative" sites, and place 5 or 6 boards at each. These could form semi-permanent sampling sites for continuous or regular monitoring, if required. This approach would improve the efficiency of the monitoring procedure as less time would be required to travel between sites. The sites could also be more carefully selected, and security of boards maximised, as the need to provide complete mapping coverage of the study area would be removed.

6.4.2 Theoretical considerations.

The present research has shown that obtaining the data to enable mapping of air pollution concentrations in the Blackbrook Valley is very difficult. The technical problems of surveying and measuring ambient air concentrations can be overcome. Over and above these considerations, there are a number of theoretical difficulties. The main "problem" is the need for detailed definition of the objectives of the survey and the requirements of the survey data, by the NCC and other organisations concerned. In relation to mapping concentrations, the following questions need to be addressed:

- what is the map to be used for?
- what is the map to show e.g. daily mean concentrations of specific pollutants, annual pollutant load, exposure/dose received?
- for what pollutants and, in relation to biological effects, for what species?
- what level of geographical resolution is required?

For mapping air pollution concentrations in the Blackbrook Valley, there is a need for a coordinated programme of air-sampling, and data collection. Biological monitors and indicators on their own are of limited value. The present research has developed a method which could be used to carry out periodic or occasional surveys of relative air pollution levels. A programme of data collection etc. should be coordinated by the local authority, who have the expertise, knowledge and records of the area to provide a framework for the necessary research. Only with this sort of basic (purpose-collected) data can any form of dispersion modelling be attempted.

The compilation of an emission inventory would be a useful means of routinising the collection and storage of the required data. However the difficulties of this should not be underestimated.

In relation to the programme of data collection, the following information is also required.

<u>Climatic data.</u> Relevant climatic data is needed for the Blackbrook Valley. Comprehensive routinely collected data for nearby areas, such as Edgbaston (Birmingham University) or Elmdon (Birmingham Airport), are readily available but not really appropriate. At best these would be good estimates of weather conditions in the study area; at worst they may be misleading. To obtain the necessary data a permanent weather station is required in the Blackbrook Valley itself. Saltwells Wood would probably be the best location for this. The presence of the Nature Centre, with an existing team of wardens, would afford some protection against vandalism of the equipment. The station itself would provide an educational facility for the reserve. Additional

meteorological data for other sites in the Blackbrook Valley could be obtained on an *ad hoc* basis and by involving local schools.

Conventional monitors. As described in Chapter 5, additional data on environmental quality needs to be collected in the Blackbrook Valley to complement the information obtained from biological monitors.

The above activities need to be planned in the context of future management plans for the Blackbrook Valley and Saltwells Wood LNR.

6.5.0 CONCLUDING REMARKS

The application of a biological monitoring method (lichen boards) has been shown to be of practical value for the study of air pollution in the Blackbrook Valley. Two surveys, based on the photographic recording and observation of colour changes in the lichen *Hypogymnia physodes* were carried out in the winters of 1983/84 and 1984/85. The two surveys revealed considerable within-site variation in pollution levels, but showed the same overall mean level of damage. Detailed description and evaluation of the methodology means that the technique can be reapplied to obtain comparative survey data for the Blackbrook valley. This thesis has described the practical and theoretical considerations for applying the method. The information can be used as the basis for more detailed study of air pollution levels.

APPENDICES

APPENDIX A

Dudley Enterprise Zone Planning Scheme

DUDLEY
Metropolitan Borough

Dudley Enterprise Zone Planning Scheme

10th July 1981

Dudley Enterprise Zone Planning Scheme

1. INTRODUCTION

1.1 The Secretary of State for the Environment, under the provisions of Section 179 of the Local Government, Planning and Land Act, 1980 and Schedule 32 of that Act, invited the Dudley Metropolitan Borough Council to prepare proposals for an Enterprise Zone Scheme for parts of the Blackbrook Valley.

1.2 As a response, the Council, following the procedures set out in the said Schedule 32, prepared a draft scheme for the purposes of publicity. Following publicity given to the draft scheme it has adopted this scheme by resolution as the Dudley Enterprise Zone Scheme, after consideration of representations made on the Draft Scheme during the period specified by the Council.

1.3 Planning permission is granted under the scheme for development within the Enterprise Zone, subject to certain exclusions, conditions and limitations. Also, particular Sub-Zones are defined where additional exclusions, limitations and conditions will apply.

1.4 The Dudley Enterprise Zone Designation Order 1981 was laid before Parliament on the 19th June 1981, and came into operation on the 10th July 1981. As a result, Dudley Metropolitan Borough is the Enterprise Zone Authority and, for the purposes of this document, the Council will hereafter be referred to as the Enterprise Zone Authority.

2. BOUNDARIES OF THE ENTERPRISE ZONE

The boundaries of the Enterprise Zone are defined by means of a map referred to in the designation order, and are shown by a black line on Plan No 1 attached. For the purpose of clarification, the land included in the Enterprise Zone is all that land within the black outlines.

3. SUB-ZONES

3.1 **The Dudley Enterprise Zone contains the following Sub-Zones:**

(a) Sub-Zone 1 is shown vertically hatched on Plan No. 1 attached.

(b) The sensitive boundaries Sub-Zones are shown horizontally hatched on Plan No. 1 attached.

(c) The Parkhead Locks, Merry Hill and Mill Street Sub-Zones are shown diagonally hatched on Plan No. 1 attached.

4. PLANNING PERMISSION – GENERAL

In accordance with the terms of the Local Government, Planning and Land Act, 1980 planning permission is granted under this scheme throughout the Enterprise Zone, except in the Parkhead Locks, Merry Hill and Mill Street Sub-Zones for development (as defined by Section 22(1) of the Town and Country Planning Act, 1971). This planning permission is subject to -

(a) the general conditions, limitations and exclusions applying throughout the Zone and set out in para. 5 below, and

(b) in the case of the sensitive boundary sub-zones and the Parkhead Locks, Merry Hill and Mill Street Sub-Zones the particular exclusions, conditions, limitations and reserved matters are set out in para. 6.

5. EXCLUSIONS AND CONDITIONS APPLYING THROUGHOUT THE ENTERPRISE ZONE

5.1 EXCLUDED DEVELOPMENT

This permission does not relate to the construction or use of buildings or to the use of land for the following purposes:

(a) Special Industrial Uses as listed in Use Classes V to IX (inclusive) of the Schedule to the Town and Country Planning (Use Classes) Order, 1972.

(b) The storage, manufacture, processing and/or use of any of the quantities of hazardous substances defined in Annex 1 attached.

(c) Any use which requires licensing under the Nuclear Installations Act, 1965.

(d) Any use which involves the disposal or treatment of waste.

(e) As an aerodrome as defined in Article 90 of the Air Navigation Order 1976 (S.I. 1783)

5.2 This permission does not relate to the change of use from a dwelling house to any other use.

5.3 Except by agreement with the Enterprise Zone Authority in consultation with the Highway Authority no development shall take place within the highway safeguarding areas which are shown on Plan No. 2 and described in Annex 2.

5.4 PLANNING CONDITIONS

(a) Except by agreement with the Enterprise Zone Authority all development consisting of the construction of new buildings hereby permitted shall contain adequate provision within the curtilage of that development for the loading and unloading of vehicles. The development shall not be brought into use until such provision is made available and the provision shall thereafter remain available at all times for the loading and unloading of vehicles in connection with the use of that development.

(b) Except by agreement with the Enterprise Zone Authority no development consisting of the use of land for open storage shall be carried out unless adequate provision is made for the loading and unloading of vehicles off the highway.

(c) Except by agreement with the Enterprise Zone Authority in consultation with the Highway Authority all vehicular accesses to an adopted highway or highway which the developer proposes for adoption shall be constructed and located in accordance with the conditions and standards specified in Annex 2 of this Scheme. Except by agreement with the Enterprise Zone Authority in consultation with the Highway Authority no alterations of an existing vehicular access to an adopted highway shall be carried out except in accordance with those standards.

(d) Except by agreement with the Enterprise Zone Authority the layout and design of foul and storm sewers to drain the proposed highways and development shall be designed and constructed in accordance with the "Developers Guide and Specification to adoption of sewers under Section 18 of the Public Health Act, 1936." issued by Severn Trent Water Authority.

(e) Where by virtue of the planning permission granted by paragraph 4 above, development is carried out consisting of the erection of or use of a building as a shop (as defined in Article 2 of the Town and Country Planning (Use Classes) Order 1972) then, notwithstanding the provisions of Section 22(2) (f) of the Town and Country Planning Act 1971 and Article 3(i) of the Use Classes Order, No more than 2,500 square metres of the gross floor space of the shop shall be used for the retail sale of food, drink, or clothing or any combination thereof.

6. EXCLUSIONS AND CONDITIONS APPLYING TO THE SUB-ZONES

6.1 SUB-ZONE 1

In addition to the matters specified in Sections 5.1, 5.2 and 5.3 above the planning permission of Sub-Zone 1 is also subject to the following exclusion:

Excluded Development: This permission does not extend to the storage and sorting in the open of scrap material.

6.2 SENSITIVE BOUNDARY SUB-ZONES

In addition to the matters specified in Sections 5.1, 5.2 and 5.3 above, the planning permission for the sensitive boundary Sub-Zones is also subject to the following exclusion and reserved matters:

Excluded Development: No development is permitted other than the construction or use of buildings for any of the purposes specified in Classes 11, 111, and X of the Schedule to the Town and Country Planning (Use Classes) Order, 1972 (offices, light industrial and wholesale warehouse or a repository).

Reserved Matters: Except with the approval of the Enterprise Zone Authority no development within the sensitive boundary Sub-Zones shall be commenced until details of the siting and height of built development and of the provision for vehicle loading, unloading, manoeuvring and parking and of associated screening and landscaping have been submitted to and approved by the Enterprise Zone Authority.

Except with the approval of the Enterprise Zone Authority, no development within the sub-zone shall be brought into use until such associated screening and landscaping has been approved and provided.

6.3 PARKHEAD LOCKS, MERRY HILL AND MILL STREET SUB-ZONES

No development is permitted under this Scheme within the Parkhead Locks, Merry Hill and Mill Street Sub-Zones (i.e. a planning application under the Town and Country Planning Act 1971 is required).

7. NORMAL PLANNING PROCEDURES

7.1 Nothing in this document precludes the right of any person to submit a planning application under the Town and Country Planning Act, 1971 for development within the Enterprise Zone.

7.2 Applications for planning permission will be dealt with in accordance with the procedures set out in Annex 3 to this Scheme. The Developers Guide to the Enterprise Zone sets out the policies that will be applied to any application for planning permission.

7.3 This scheme does not authorise the carrying out of operations after the termination date of the Enterprise Zone, even if they started to be carried out before that date in accordance with the scheme.

8. ADVICE ON OTHER REQUIREMENTS

8.1 Any development proposed within the Enterprise Zone must comply with the Building Regulations 1976, (S.I. 1976 No 1676 as amended). Such applications will be dealt with in accordance with the procedures set out in Annex 3 to this Scheme.

8.2 The provisions of this Scheme do not exempt development from any other statutory requirements other than the requirements of Part III of the Town and Country Planning Act, 1971, that planning permission shall be obtained for development.

8.3 The statutory provisions and standards relating to Health and Safety, pollution and nuisance apply throughout the Enterprise Zone. Measures proposed to minimise noise, vibration, odours and emissions to the atmosphere shall be in accordance with the guidelines contained in the developers guide.

Annex 1

ENTERPRISE ZONES

DOE CIRCULAR 1/72 APPENDIX 1

INDUSTRY	MATERIALS INVOLVING RISK	TOTAL STORAGE QUANTITY REQUIRING DETAILED INVESTIGATION
Petrochemical* and plastic polymer manufacture	All	#
Other chemical works	Acrylonitrile Ammonia Bromina Chlorine Ethylene Oxide Hydrogen Cyanide Phosgene Sulphur Dioxide	50 Tons 250 Tons 100 Tons 25 Tons 20 Tons 50 Tons 5 Tons 50 Tons
Fertiliser manufacture	Ammonia	250 Tons
Aluminium and magnesium powder production	All	#
Aluminium refining	Chlorine	25 Tons
Paper pulp manufacture	Chlorine Sulphur Dioxide	25 Tons 50 Tons
Air liquification plants and steel works	Liquid Oxygen	135 Tons
Flour and sugar silos	Flour Refined White Sugar	200 Tons 200 Tons
All	Liquified Petroleum Gas	100 Tons

\# Economic size of plant would involve such quantities of materials that the risk would invariably be present.

* Petrochemical manufacture is defined as the manufacture of chemicals from an oil refinery product or from natural gas.

Note The list given above is taken from DOE Circular 1/72 Appendix 1. This may from time to time be extended or amended by subsequent enactments or circulars. When this happens the scheme will be amended accordingly under the procedures in Clauses 9 to 13 of Schedule 32 of the Local Government, Planning and Land Act, 1980. It is essential therefore that a developer who is in doubt about whether his proposal might be covered by the latest requirements should check with the Enterprise Zone Authority.

ANNEX 2

POLICIES ON HIGHWAY MATTERS WITHIN THE ENTERPRISE ZONE

1. Improvement Lines

1.1 The Highway Authority has approved improvement lines to the following lengths of existing road within the Zone which must be protected from development:(the related highway safeguarding areas are shown on Plan No. 2)

(a) A.4036, Pedmore Road, north of Peartree Lane.
(b) Peartree Lane (whole length).
(c) A.4100, Mill Street.
(d) Two Woods Lane (whole length).
(e) A.461 Dudley Road.
(f) New Road.
(g) Blackbrook Road.
(h) The Sling.
(i) Link road between Mill Street and Merry Hill.

1.2 The following policies shall also apply:-

(a) The Blackbrook Road line is to give access to the site and may be varied or omitted by agreement between the developer and the Highway Authority provided adequate alternative access is provided.

(b) The construction of the new link road (item i) is the subject of agreements between the Highway Authority and respective landowners. The line shown may be varied by up to 100 metres from the proposed centre line with the agreement of both landowners and the Highway Authority.

(c) The existing vehicular link between Pedmore Road and Lodge Farm Estate is to be retained for light vehicles only. Accordingly the development of sites adjacent to this road is expected to make provision to accommodate its continued existence. However, the alignment of this road may be altered to suit the needs of the development, after consultation with the Highway Authority. It is necessary, for any new length of highway between Pedmore Road and the access to Lodge Farm Estate to be built to adoption standards.

2. Vehicular Access to Highways

2.1 The location and design of vehicular access from any proposed development in the Enterprise Zone to an adopted highway or highway proposed for adoption shall be in accordance with the policies and standards set out below. Details of any vehicular access which does not conform to these standards shall be subject to the agreement of the Enterprise Zone Authority in consultation with the Highway Authority. The Highway Authority will have regard to certain criteria when assessing such proposals based upon national standards and guidance laid down in Roads in Urban Areas, D.O.E. Technical Memorandum H11/76 (as amended) and Development Control Policy Note No.6.

2.2 The construction of a new vehicular access to any part of the Enterprise Zone is not permitted from:-

(a) Merry Hill/Pedmore Road
(b) Terrace Street
(c) The Wallows
(d) Mill Street between Nos. 187 & 191 Mill Street

2.3 Direct access to the link road between Mill Street and Merry Hill is not permitted without the agreement of the Enterprise Zone Authority in consultation with the Highway Authority and will not normally be granted. Direct access to Merry Hill/Pedmore Road will not be permitted.

2.4 Visibility splays to protect the safety of users of the highway are required. Visibility shall be obtainable between points 1 metre above the road level over the area defined by :-

(a) a distance 'X' metres along the centre line of the minor road from the nearside edge of the major road carriageway along the centre line of the minor road;

(b) a distance 'Y' metres from the centre line of the minor road measured along the nearside edge of the major road carriageway fronting the site.

Access To	'X' Distance	'Y' Distance
Merry Hill/Pedmore Road	No access permitted.	
Terrace Street	"	
The Wallows	"	
Mill Street between Nos. 187 & 191	"	
Mill Street	9 metres	60 metres
Cinder Bank	"	"
Dudley Road	"	"
Peartree Lane	"	"
Level Street	"	"
New Link Road between A.4039 and A.4100	(See Paragraph 2.1)	
Two Woods Lane	4.5 metres	60 metres
Industrial Estate Road	4.5 metres	60 metres

2.4 Heavy duty footway crossings constructed to the attached specification are permitted for single user site accesses. On the Sling, Two Woods Lane, and adoptable industrial estate roads there will be no objection to the developer constructing the crossing provided the appropriate notice is given to the District Council Engineer, Statutory Undertakers notified and indemnity completed. No such access will be constructed within 20 metres of a road junction, without the prior approval of the Enterprise Zone Authority in consultation with the Highway Authority.

2.5 For multiple user site accesses, a standard junction layout with kerb radii of 15 metres is required.

ANNEX 3

ADMINISTRATIVE ARRANGEMENTS FOR PLANNING AND BUILDING CONTROL PROCEDURES

1. All applications for determination under the Building Regulations will be determined by the Chief Building Control Officer, on behalf of the Director of Planning and Development, or his nominee. Every endeavour will be made to determine the applications within 14 days of the receipt of a complete application by the Authority, where possible within the bounds of contemporary procedures and practices associated with the Regulations.

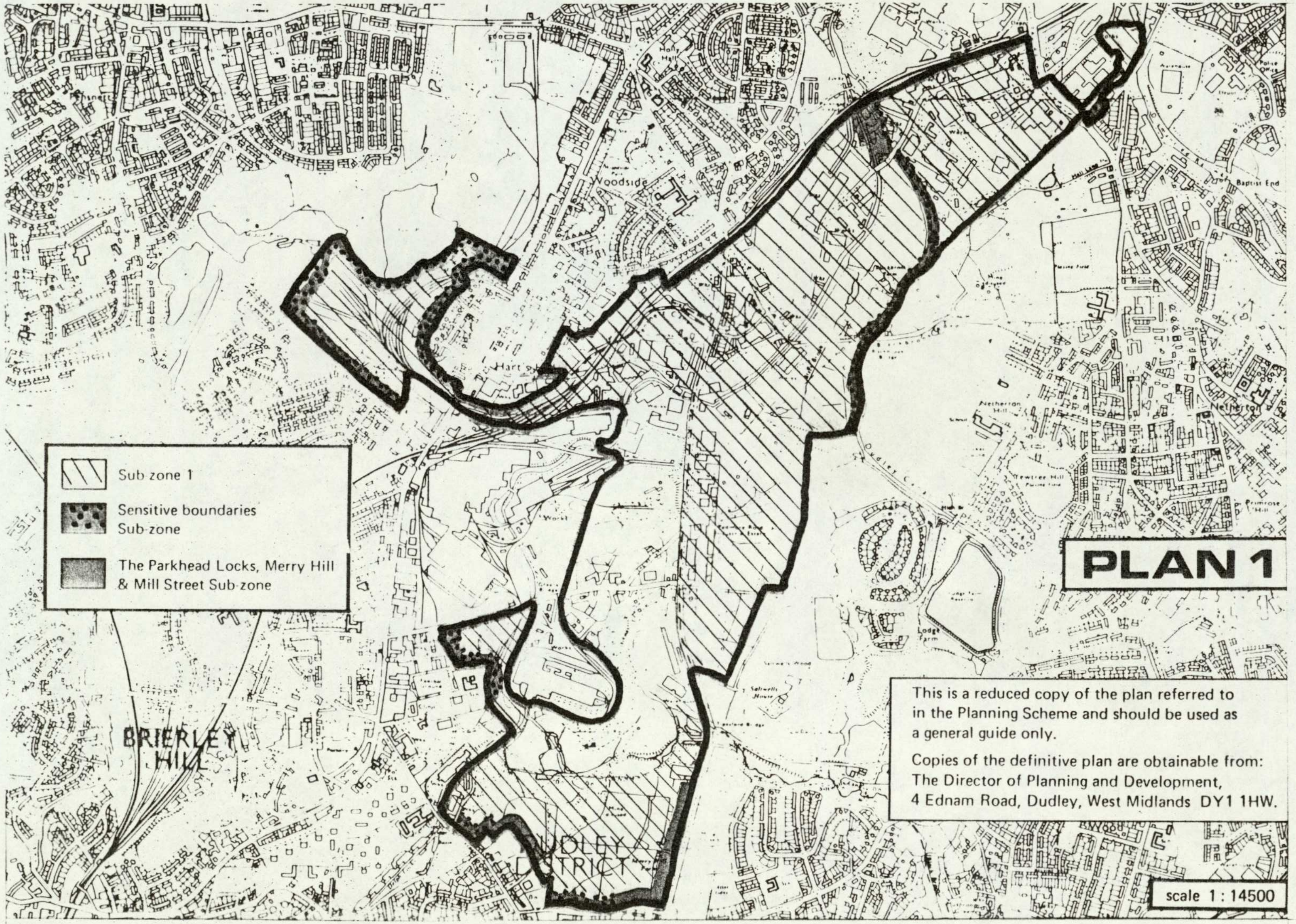
2. All applications for the relaxation of Building Regulations will be dealt with by the Chief Building Control Officer, on behalf of the Director of Planning and Development, or his nominee, following any necessary consultations with the Department of the Environment, and the concurrence of the Chairman of the Highways and Planning Committee.

3. All applications for planning permission and approval of reserved matters including proposed developments involving the storage, manufacture, processing or use of hazardous substances in major hazard quantities will be determined by the Director of Planning and Development, or in his absence, the Assistant Director of Planning and Development (Implementation) or his nominee following any necessary consultations with the Chairman of the Highways and Planning Committee, the Shadow Chairman and the Leader of the Council or their nominated deputies in their absence. Every endeavour will be made to determine applications not deemed to have planning permission by this scheme within 14 days of receipt by the Authority of a complete application . All contemporary procedures and practices associated with the determination of Planning Applications will apply.

4. All applications for a determination under the provisions of Section 53 of the Town and Country Planning Act, 1971, and related to this deemed planning permission will be dealt with immediately by the Assistant Director of Planning and Development (Implementation) on behalf of the Director of Planning and Development, or his nominee.

5. All submissions for compliance with existing and future statutory provisions, British Standards and Codes of Practice relating to health and safety, pollution and nuisance, and measures to minimise noise and vibration, odour emissions to the atmosphere, and emissions of hazardous materials shall be dealt with by the Director of Environmental Health or his nominee, following appropriate consultations with the Health & Safety Executive.

Fig. A1 Map of the Dudley Enterprise Zone showing location of sub-zones.



Source: adapted from Dudley Enterprise Zone Planning Scheme.(1)

APPENDIX B

Study of available information on air pollution emissions and sources for the Blackbrook Valley.

APPENDIX B Study of information on air pollution emissions and sources for the Blackbrook Valley.

The use of an emission inventory was considered as a means of compiling data on sources of air pollution emissions in the Blackbrook Valley. The following describes the results of a study conducted to examine possible approaches for obtaining the required information. The work was undertaken in the period May to August 1983. Three sources of information were considered, namely

1. Dudley Metropolitan Borough Enterprise Zone (Annual) Survey
2. Collection of data by questionnaire
3. Fuel suppliers

Enterprise Zone (Annual) Survey

Dudley Council carries out an annual survey as part of its procedures for monitoring the progress of the Enterprise Zone. The survey takes the form of a mini-questionnaire, including a request for information on air pollution. The survey returns for 1982 were examined as a possible source of information on air pollution emissions in the Blackbrook Valley.

The information in the Enterprise Zone annual survey was not found to be sufficiently detailed for the compilation of an emissions inventory or for definition of point sources. As shown overleaf, the survey forms requested information on a number of technical details. However the format of the questionnaire itself was not of a style which would be useful in obtaining the required information. In particular, to carry out the necessary calculations to determine emissions, further information was required for a number of factors e.g. seasonal fuel-use patterns, on ratings of boilers, hours of operation, % fuel used for

DUDLEY METROPOLITAN BOROUGH ENTERPRISE ZONE
SURVEY OF EXISTING PREMISES WITHIN ZONE.

Name of Company : Date :

Address of Company : EHO :

Telephone No. :

Representative/Position :

Company Contact re Enterprise Zone :

Owner of Company :

Owner of Lane :

Area of Site :

Area Available for Development :

Business :

Alkali Process : Use Class :

Hours of Works :

Future Plans : 1. Land acquisition :

2. Structural development :

3. New processes :

4. New plant :

5. New materials :

6. Air Pollution / Noise effect :

7. Planning permissions not implemented :

8. Employees - Male (full-time)
Male (part-time)
Female (full-time)
Female (part-time)

Details of Processes :

(All plant contributory to Atmospheric Pollution, i.e. boiler, furnace, cupola incinerator, grinding machine, etc.).

AIR POLLUTION INFORMATION

Plant :

+ Rating :

Stack Height :

Efflux Velocity :

Back End Temperature :

Terminal Temperature :

Products of Emission :
(SO_2 fume dust grit smell smoke).

Quantities of Emission :

Arrestation Equipment :

Fuel :

Rate of fuel use :

Total Winter fuel use :
Oct - Mar

Total Summer fuel use :
April - Sept

Name of Supplier :

NOISE POLLUTION INFORMATION

Noise/Vibration Sources :

Noise/Vibration Control :

HAZARDOUS INSTALLATIONS

Materials :

Emissions/Quantities :

Waste Products :

Disposal :

space and process heating, and on emission rates. The standard of completion of survey forms was also found to be inadequate, with entries often missing or made in pencil.

The incompleteness of the returns, combined with the lack of different categories of information, effectively prevented sufficient relevant information being available for the present research. To obtain the required information it would be necessary to use an alternative approach or to consult additional sources of information or published data. A number of alternative options were considered. These were:

1. to consider the possibility of modifying the existing survey forms or using a purpose-made questionnaire.
2. to approach fuel suppliers in the area

The results of these approaches are now described.

<u>Questionnaire approach</u>

As a means of obtaining emission inventory data, the questionnaire approach has been used successfully in a number of UK studies, notably (as discussed in section 2.1.3) the Greater London Council.[1] However, because of the nature of the Enterprise Zone, the same direct approach was not possible in the Blackbrook Valley.

The Enterprise Zones were introduced by the Conservative Government on an experimental basis in 1980. The idea was to see how far industrial and commercial activity would be encouraged by the removal of certain tax burdens, and by simplifying the system of statutory and administrative controls. In a document outlining the Enterprise Zone scheme one of the benefits listed was that "government requests for statistical information will be reduced."[2] In view of this situation, the idea of undertaking a questionnaire was discouraged by the research supervisory team and Dudley Council, particularly as information on air pollution was already being obtained routinely in the Enterprise Zone (Annual) Survey. The alternative idea of improving the survey forms was considered and discussed with Dudley Council (Pollution Division). Some minor changes were made to the Annual Survey form. The results of these changes on subsequent survey returns were not studied.

Fuel Suppliers

Direct approaches were made to organisations representing the different major fuels used in the Dudley area. This was with a view to determining the quantities of different types of fuels supplied to different categories of users in the Dudley Metropolitan Borough.

In the first instance a more or less standard letter (see page 216) was sent out to each of the organisations which had been identified as a potential source of information. The specific information requested was as follows :

1. Type and composition of fuels supplied.

2. Total annual quantities of each fuel supplied to different categories of user, namely

   Domestic (private households)
   Industrial
   Institutional/Commercial

   The last category comprises users not included in the other categories e.g. shops, hospitals, schools. The distribution and proportion of all categories in specific areas would be identified from Local Authority Land Use Classification data.

3. For each user category, the amount of fuel (or percentage of annual fuel) supplied seasonally i.e. defined as

   summer months (April - September)
   winter months (October - March).

4. The most recent yearly figures available, and if possible the average of the previous 5 years figures for comparative purposes.

Three types of fuel suppliers were approached, namely solid fuel, petroleum fuel and gas. The responses of these organisations, and usefulness of the information obtained, were variable. An account of the results is presented in the following three sections.

Solid Fuel (i.e. coal, coal substitutes)

The initial request for information on solid fuels was made to the Solid Fuel Advisory Service. The letter was eventually passed to the district sales manager of the National Coal Board (NCB) for the district office covering the Metropolitan Borough of Dudley.

The reply resulting from this enquiry indicated that the required information for solid fuels was not collected by the NCB. The National Coal Board is not responsible for the delivery of specific fuels; this is organised through wholesale and smaller retail outlets. The respondent offered the opinion that the only way to obtain the required information would be by a door-to-door survey to identify premises using solid fuel and specifically which type of solid fuel (see page 218). This type of approach would involve a lot of time. Other sources of information probably exist which would be more accessible or more useful. An example of a different approach which could be tried is found in the study of Maughan *et al.*[3] The purpose of this study was to assess the impact on air quality, measured in terms of smoke and sulphur dioxide SO_2, of a new power station development being undertaken by the Electricity Supply Board in Dublin. An emission inventory was already available for this study.[4]

Coal is the major domestic fuel used in the Dublin urban area. In the above inventory the apportioning of the domestic fuel consumption was done on the basis of household survey information. These included:

(i) housing density - obtained from the 1971 Census, which was the most recent at that time

(ii) household expenditure on the different fuels, obtained from the Household Budget Survey for the years 1973 - 1978

Petroleum Fuels

Approaches were made by telephone and/or by letter to a number of the main petroleum companies identified from the Yellow Pages of the telephone directory for the Dudley area. None of these approaches resulted in useful direct information. Companies were either unprepared to offer information on sales or unable to provide the specific information required.

Shell Ltd. did offer some useful indirect information. Through Shell I was able to contact UK Petroleum Industrial Association (UK PIA) Ltd. Through this organisation ten major suppliers of petroleum products contribute data on sales to a computer system called PINGAR (Petroleum Industrial National Grid Area Reporting). The data identifies deliveries of oil products for the whole of the UK using standard 10 km grid square references. In addition, for major urban conurbations, there is a more detailed collection of information at 1 km grid resolution.

The secretary of the statistical committee, made some information available for this study. This is included on p.222-223. The information was supplied for the two 10 km grid squares which cover the Dudley area. Unfortunately information at the smaller 1 km scale was not available for the Dudley area.

Data contributed to the PINGAR system did not present a complete picture of sales. The information given provided a measure of the accuracy involved (see letter p. 220). Nevertheless some useful and detailed information was obtained conforming to the types of fuel categories requested for the fuels survey. Furthermore this information would not have been available through a direct approach to the retailers.

<u>Gas data</u>

The West Midlands Gas Board collects detailed information on gas sales for the whole of the West Midlands County. Monthly information on each premises using gas is stored on computer. The information collected was related to the system of tariffs. Gas is sold in a number of ways, namely

1. direct tariff (coin/slot meters)
2. indirect tariff (billed)
3. contract

The main users in category 1 are domestic premises. Category 2 includes domestic, commercial and industrial users. Large industrial users agree to use a set amount of fuel in a given period. The gas sold in this way is charged at a preferential (cheaper) rate i.e. category 3. Records are updated each year in March.

When this survey was conducted in 1983 there were two systems in operation for storage and retrieval of data records.

(a) For individual premises. The data in this programme could be accessed on a coded street by street basis, for individual streets. By careful selection of street codes the data could be accessed to correspond with specific postal areas.

(b) For the borough. On a separate programme information was also available for each county borough as yearly totals covering the period from 1972 onwards.

Using the first programme, street codes for individual streets or for groups of streets were scanned for the Blackbrook Valley study area. Sample printouts of the data (excluding slot, which appeared on a separate printout) for Blackbrook Road, Peartree Lane and Pedmore Road are shown on pages 224 to 226. Page 227 shows a printout of gas data for boroughs of the West Midlands County, in 1983.

THE UNIVERSITY OF ASTON IN BIRMINGHAM
Gosta Green, Birmingham, B4 7ET/Tel: 021 359 3611 Ex

Department of Environmental and Occupational Health

Head of Department: Professor R T Booth PhD, DIC, FIMechE, CEng, MIOSH

Your Ref.
Our Ref.

17 June 1983

Solid Fuel Advisory Service
Fuel House
1 Vicarage Lane
Water Orton
B46 1RY

Dear Sir

I am conducting a PhD research project concerning the ecological impact of pollution on an area in the West Midlands, namely the Blackbrook Valley in the Metropolitan Borough of Dudley. In order to establish a baseline for this work I need to compile an inventory of air pollution emission sources in an around the study area. Hopefully data from this can then be linked to any ecological effects, in particular on vegetation, by means of simple modelling. The project is being carried out in collaboration with Dudley Local Authority and the Nature Conservancy Council.

To construct the emission inventory it will be necessary to use information from a number of different sources, partly to provide a means of cross-checking data and also to supplement data where this is incomplete. The main industrial premises in the Blackbrook Valley are situated in the Dudley Enterprise Zone. This area is practically free from the usual bureaucratic and planning controls and hence, although the Local Authority has some data on industrial emissions, the possibilities for obtaining detailed information by direct inquiry eg, a questionnaire are limited. An alternative method, which would also give information on emission from sources other than industrial, would be to consider the types and quantities of different fuels supplied in the Dudley Metropolitan Borough and to relate these to known emission factors. In this connection I hope you may be able to help me with information on solid fuels.

The particular information I require is as follows:

1. Types of solid fuels supplied, with average sulphur and ash content.
2. For each of the above fuel types, the total annual quantity supplied to different categories of user, namely

   Domestic (private households)
   Industrial
   Institutional/Commercial (users not included in the above, shops, hospitals, schools, etc)

/continued .....

Telex 336997

2. continued

   The distribution and proportion of these categories in specific areas will be identified from Land Use Classification data.

3. For each fuel type and each user category, the annual quantity of fuel (or percentage of total annual fuel) supplied seasonally ie, during the summer months (April - September), and during the winter months (October - March).

4. The most recent yearly figures available, and if possible the average of the previous 5 years for comparison.

Could you tell me whether you have any of this information available and if so, whether it could be related to the requirements outlined. If there were likely to be difficulties eg, incompatibility with the district classification or user categories which you use, perhaps you could contact me by telephone, when I would be happy to discuss these further. Alternatively, if convenient with you, I can arrange to visit the Advisory Service.

Yours faithfully

CATHERINE F WILSON, BSc

Please reply to: 2A Goldsmith Road, Kings Heath, Birmingham B14 7EE.

National Coal Board
Midlands Sales Region
South Staffordshire Sales District No. 46
65 Waterloo Road, Wolverhampton

Marketing Department

NCB

Our ref 46/3/13
Your ref

Miss C.F. Wilson, B.Sc.,
2A Goldsmith Road,
Kings Heath,
Birmingham,
B14 7EE.

29th June 1983.

Dear Miss Wilson

Your letter of the 17th instant has been forwarded on to me from our Birmingham office and you have already been informed that this is the District office of the N.C.B. covering the Blackbrook Valley area in the Metropolitan Borough of Dudley.

I note with interest the research project with which you are concerned and naturally I would be pleased to help in any way possible, however, I must point out that the N.C.B. is not responsible for the delivery of specific fuels but various types of premises in the area are and therefore there is no information available on the number of premises using Solid Fuel. Such fuel would be purchased locally from one of a large number of Coal Merchants offering a wide range of Solid Fuels.

In my opinion the only way to obtain information would be by a door to door survey which could identify those premises using Solid Fuel and specifically which type of Solid Fuel. If having done this specific fuels can be identified then information regarding these can be made available to you.

If you feel that you would like to discuss this matter with me please do not hesitate to contact me so that a discussion can be arranged at our mutual convenience.

Yours sincerely

J D Roberts

J D Roberts
Sales District Manager

Telephone: Wolverhampton 772621 Ext.

TOTAL

TOTAL OIL Great Britain Ltd

Miss C.F. Wilson,
2A, Goldsmith Road,
Kings Heath,
Birmingham, B14 7EE.

SOUTHERN REGION.
VICTORIA HOUSE.
VICTORIA ROAD.
BUCKHURST HILL.
ESSEX IG9 5ES
TELEPHONE: 01-504 7676
TELEX: 897042
REGISTERED OFFICE:
33 CAVENDISH SQUARE LONDON W1M 0JE
REGISTERED IN ENGLAND No. 553535

YOUR REF.:

OUR REF.: S/GBS/GM/SEH

23rd August, 1983

Dear Miss Wilson,

Your letter dated 14th July, 1983, concerning the sales of Petroleum Fuels in the Blackbrock Valley area of Dudley, has been passed to me.

Unfortunately the information you require, for such a small area, is not available as far as Total Oil is concerned.

If we can assist in any other way, please do not hesitate to contact me.

Yours sincerely,

S E Hutton (Mrs)

PP GARY MARTIN
General Business Supervisor (Midlands)

Economics & Statistics Group

United Kingdom
Petroleum Industry Association Limited

Reply to :

Tel:

Miss C F Wilson
2a Goldsmith Rd
Kings Heath
Birmingham
B14 7EE

Dear Miss Wilson

DELIVERIES OF PETROLEUM PRODUCTS IN THE BLACKBROOK VALLEY

I refer to your letter of 14 July addressed to , which was passed to me for consideration, and to our subsequent telephone conversations, and am pleased to enclose the statistics you require for various products delivered in the period 1979-1982. The numbers given are in the standard units of measure of 100's litres, and should you wish to convert to tonnes, the following factors should be applied:

	1979	1980	1981	1982
Motor Spirit	1345	1345	1345	1340
Derv Fuel	1190	1185	1185	1185
Burning Oil	1266	1260	1260	1255
Gas/Diesel Oil	1190	1185	1185	1185
Fuel Oil	1040	1040	1035	1035

NB The above are litres/tonne rates

The statistics provided have been extracted from an oil industry reporting system known as PINGAR (Petroleum Industry National Grid Area Reporting) which is a method of identifying deliveries within standard 10 kilometer grid square references, or, in the case of major urban connurbations, 1 kilometer grid square references. The following points about PINGAR data should be borne in mind:

Due to the computing power needed to provide data into the system, only ten major oil companies are able to contribute. Taken in conjunction with the fact that the figures for Gas/Diesel and Fuel Oil specifically exclude deliveries for Public Gas/Making and Electricity Generation, this means that it is a known fact that at the Total UK level, when measured against another reporting system with wider coverage (but not at grid square level), PINGAR data in overall content averages out at around 80-85% of the numbers accepted as definitive Total UK consumption data. The relevance of this shortfall to a specific area cannot of course be judged as there is no yardstick by which to measure it.

Finally, may I emphasise that the cost of an interrogation of PINGAR tape files is somewhat prohibitive, and would normally be passed on to the user. We are pleased to say that in your case this is not contemplated, but we do not wish to create a precedent. In other words, would you please keep this 'under your hat'.

Yours sincerely

[signature]

RP.
A E Truett
Secretary
Statistical Committee

P.S. Unfortunately for your requirements, we found on inspection that Dudley does not fall into a major urban conurbation and, therefore, the information you requested is not available on a 1km grid square basis. We have done the only thing we could and given you the two 10km squares. I hope that this will be of some help.

[signature]

2.8.83

VOLUME IN HUNDREDS OF LITRES

GRID SQUARE: 3928	SUMMER 1979	WINTER 1979-80	SUMMER 1980	WINTER 1980-81	SUMMER 1981	WINTER 1981-82	SUMMER 1982
MOTOR SPIRIT	398188	518020	401984	414395	429982	359692	554127
DERV	102468	146218	96130	101178	92812	93123	130291
BURNING OIL	16278	34530	8709	17018	8664	61239	10715
GAS/DIESEL - DOMESTIC	30851	94652	16600	47796	14743	46785	35332
GAS/DIESEL - INDUSTRIAL	70567	189875	55688	93207	39525	82603	57641
GAS/DIESEL - COMMERCIAL	98661	212724	32106	94087	83306	278838	125546
FUEL OIL - DOMESTIC	0	0	0	0	0	0	0
FUEL OIL - INDUSTRIAL	88065	180394	52867	21407	8600	157488	225745
FUEL OIL - COMMERCIAL	94136	214830	72366	243918	133191	235924	80526
LIGHT FUEL OIL TOTAL	50234	59122	18021	8861	9776	14121	24288
MEDIUM FUEL OIL TOTAL	15912	38951	12406	6328	1918	33098	70165
HEAVY FUEL OIL TOTAL	116051	297128	94805	250136	130097	346195	211821
TOTAL VOLUME	1081411	1986444	861682	1298331	952614	1709106	1526197

GRID SQUARE: 3929	SUMMER 1979	WINTER 1979-80	SUMMER 1980	WINTER 1980-81	SUMMER 1981	WINTER 1981-82	SUMMER 1982
MOTOR SPIRIT	652472	880846	651699	631760	599613	591863	847946
DERV	202211	275897	190601	182840	167816	162928	253855
BURNING OIL	28042	71534	18696	36981	16915	34997	18197
GAS/DIESEL - DOMESTIC	35710	88716	26022	55524	23306	52317	41254
GAS/DIESEL - INDUSTRIAL	136215	400223	148071	169729	72224	165240	115847
GAS/DIESEL - COMMERCIAL	115071	303512	105176	178150	95669	171305	152981
FUEL OIL - DOMESTIC	0	0	0	0	0	0	0
FUEL OIL - INDUSTRIAL	386685	505605	134309	198090	125811	198851	185124
FUEL OIL - COMMERCIAL	25647	85411	32349	50372	23407	47587	42226
LIGHT FUEL OIL TOTAL	19573	41961	14221	8014	4519	8222	6329
MEDIUM FUEL OIL TOTAL	33687	101813	37234	49795	22593	37710	30874
HEAVY FUEL OIL TOTAL	359078	447198	115200	190654	122106	200506	190147
TOTAL VOLUME	1994391	3202716	1473578	1751909	1273979	1671524	1884780

IR HQF381 PINGAR ANALYSIS - DUDLEY AREA DATE 010883 PAGE 2

VOLUME IN HUNDREDS OF LITRES

SUMMARY	SUMMER 1979	WINTER 1979-80	SUMMER 1980	WINTER 1980-81	SUMMER 1981	WINTER 1981-82	SUMMER 1982
MOTOR SPIRIT	1050660	1398866	1053683	1046155	1029595	951556	1402073
DERV	304679	422115	286731	284018	260628	256049	384146
BURNING OIL	44320	106064	27405	53999	25579	96236	28912
GAS/DIESEL - DOMESTIC	66561	183368	42622	103320	38049	99102	76586
GAS/DIESEL - INDUSTRIAL	206782	590098	203759	262936	111749	247843	173488
GAS/DIESEL - COMMERCIAL	213732	516236	137282	272237	178975	450143	278527
FUEL OIL - DOMESTIC	0	0	0	0	0	0	0
FUEL OIL - INDUSTRIAL	474750	685999	187176	219497	134411	356339	410869
FUEL OIL - COMMERCIAL	119783	300241	104715	294290	156598	283512	122752
LIGHT FUEL OIL TOTAL	69807	101083	32242	16875	14295	22343	30617
MEDIUM FUEL OIL TOTAL	49599	140764	49640	56123	24511	70808	101039
HEAVY FUEL OIL TOTAL	475129	744326	210005	440790	252203	546702	401968
TOTAL VOLUME	3075802	5189160	2335260	3050240	2226593	3380630	3410977

OJH2 BLACKBROOK RD (471355)

	SLOT		DOM CRED WITH CH		DOM CRED NO CH		INDUSTRIAL		COMM+PA+PL	
			(INCL ERRORS)		(INCL NO INFO)					
THMS RANGE	THMS	CUSTS	THMS	CUSTS	THMS	CUSTS	THMS	CUSTS	THMS	CUSTS
50.	0.	0.	0.	0.	0.	2.	0.	0.	0.	0.
100.	0.	0.	0.	0.	0.	2.	0.	0.	0.	0.
200.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
300.	0.	0.	0.	0.	494.	2.	0.	0.	0.	0.
400.	0.	0.	0.	0.	790.	2.	0.	0.	0.	0.
500.	0.	0.	416.	1.	922.	2.	0.	0.	0.	0.
600.	0.	0.	0.	0.	1701.	3.	0.	0.	0.	0.
700.	0.	0.	0.	0.	657.	1.	0.	0.	0.	0.
800.	0.	0.	0.	0.	790.	1.	0.	0.	0.	0.
900.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1250.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1500.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1750.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2500.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3500.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4500.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
5000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
6000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
8000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
10000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
20000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
25000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
30000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
35000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
40000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
45000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
50000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
75000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
100000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.1E 71	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
HISTOG TOT	0.	0.	416.	1.	5355.	13.	0.	0.	0.	0.
ALL CUSTS		0.		1.		17.		0.		0.

C.HTG OWNERSHIP (DOM CRED ONLY)

	THMS	CUSTS IN HISTOG	TOTAL CUSTS
NO CHTG	5355.	12.	14.
NO INFO	0.	1.	3.
SB	416.	1.	1.
WA	0.	0.	0.
ERRORS(=WA?)	0.	0.	0.
TOTAL	5771.	14.	18.

OTHER ERRORS   SLOT/CREDIT DES (COUNTED AS SLOT) 0   CREDIT SUB CLASS (COUNTED AS COMM) 0

OJH2 PEARTREE LA (468220)

THMS RANGE	SLOT THMS	SLOT CUSTS	DOM CRED WITH CH (INCL ERRORS) THMS	DOM CRED WITH CH (INCL ERRORS) CUSTS	DOM CRED NO CH (INCL NO INFO) THMS	DOM CRED NO CH (INCL NO INFO) CUSTS	INDUSTRIAL THMS	INDUSTRIAL CUSTS	COMM+PA+PL THMS	COMM+PA+PL CUSTS
50.	0.	0.	0.	0.	0.	0.	0.	5.	0.	0.
100.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
200.	0.	0.	0.	0.	117.	1.	0.	0.	0.	0.
300.	0.	0.	0.	0.	285.	1.	0.	0.	0.	0.
400.	0.	0.	388.	1.	0.	0.	0.	0.	0.	0.
500.	0.	0.	0.	0.	864.	2.	0.	0.	0.	0.
600.	0.	0.	0.	0.	549.	1.	0.	0.	0.	0.
700.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
800.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
900.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1250.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1500.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1750.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2500.	0.	0.	0.	0.	0.	0.	2379.	1.	2251.	1.
3000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3500.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4500.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
5000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
6000.	0.	0.	0.	0.	0.	0.	5087.	1.	0.	0.
7000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
8000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9000.	0.	0.	0.	0.	0.	0.	8613.	1.	0.	0.
10000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15000.	0.	0.	0.	0.	0.	0.	11007.	1.	0.	0.
20000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
25000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
30000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
35000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
40000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
45000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
50000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
75000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
100000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.1E 71	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
HISTOG TOT	0.	0.	388.	1.	1815.	5.	27086.	9.	2251.	1.
ALL CUSTS		0.		1.		5.		10.		1.

C.HTG OWNERSHIP (DOM CRED ONLY)

	THMS	CUSTS IN HISTOG	TOTAL CUSTS
NO CHTG	1815.	5.	5.
NO INFO	0.	0.	0.
SB	388.	1.	1.
WA	0.	0.	0.
ERRORS(=WA?)	0.	0.	0.
TOTAL	2203.	6.	6.

OTHER ERRORS   SLOT/CREDIT DES (COUNTED AS SLOT) 0   CREDIT SUB CLASS (COUNTED AS COMM) 0

OJH2 PEDMORE RD (468230)

THMS RANGE	SLOT THMS	SLOT CUSTS	DOM CRED WITH CH (INCL ERRORS) THMS	DOM CRED WITH CH (INCL ERRORS) CUSTS	DOM CRED NO CH (INCL NO INFO) THMS	DOM CRED NO CH (INCL NO INFO) CUSTS	INDUSTRIAL THMS	INDUSTRIAL CUSTS	COMM+PA+PL THMS	COMM+PA+PL CUSTS
50.	0.	0.	0.	0.	2.	1.	0.	0.	0.	0.
100.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
200.	0.	0.	0.	0.	694.	4.	0.	0.	0.	0.
300.	0.	0.	0.	0.	999.	4.	0.	0.	0.	0.
400.	0.	0.	0.	0.	673.	2.	0.	0.	0.	0.
500.	0.	0.	0.	0.	1349.	3.	0.	0.	0.	0.
600.	0.	0.	0.	0.	1638.	3.	0.	0.	0.	0.
700.	0.	0.	0.	0.	1996.	3.	0.	0.	0.	0.
800.	0.	0.	0.	0.	0.	0.	767.	1.	0.	0.
900.	0.	0.	0.	0.	1689.	2.	0.	0.	0.	0.
1000.	0.	0.	0.	0.	900.	1.	0.	0.	0.	0.
1250.	0.	0.	0.	0.	1081.	1.	0.	0.	1218.	1.
1500.	0.	0.	0.	0.	0.	0.	0.	0.	1302.	1.
1750.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2000.	0.	0.	0.	0.	0.	0.	0.	0.	3897.	2.
2500.	0.	0.	0.	0.	2081.	1.	2391.	1.	2096.	1.
3000.	0.	0.	0.	0.	2867.	1.	0.	0.	0.	0.
3500.	0.	0.	0.	0.	0.	0.	3220.	1.	0.	0.
4000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4500.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
5000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
6000.	0.	0.	0.	0.	0.	0.	0.	0.	5916.	1.
7000.	0.	0.	0.	0.	0.	0.	6568.	1.	0.	0.
8000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
10000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
20000.	0.	0.	0.	0.	0.	0.	0.	0.	18815.	1.
25000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
30000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
35000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
40000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
45000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
50000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
75000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
100000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.1E 71	0.	0.	0.	0.	0.	0.	1037885.	1.	0.	0.
HISTOG TOT	0.	0.	0.	0.	15969.	26.	1050831.	5.	33244.	7.
ALL CUSTS		0.		0.		29.		7.		20.

C.HTG OWNERSHIP (DOM CRED ONLY)

	THMS	CUSTS IN HISTOG	TOTAL CUSTS
NO CHTG	13102.	25.	27.
NO INFO	2867.	1.	2.
SB	0.	0.	0.
WA	0.	0.	0.
ERRORS(=WA?)	0.	0.	0.
TOTAL	15969.	26.	29.

OTHER ERRORS   SLOT/CREDIT DES (COUNTED AS SLOT) 0   CREDIT SUB CLASS (COUNTED AS COMM) 0

***D.RASTATS 3W** Scaled to published Regional totals, with gas sales temp corrected and interruption added back.

* includes manually billed commercials when split not available.

			DOMESTIC CREDIT				SLOT		IND			COMM		
					GAS	GAS			COMPUTER	MANUAL*		COMPUTER	MANUAL	
			TH THM	CUSTS	WA	SB	TH THM	CUSTS	TH THM (TARIFF)	TH THM (CONTRACT)	CUSTS	TH THM (TARIFF)	TH THM (CONTRACT)	CUSTS
MAR 83	1	BHAM	177923.	320407.	29279.	129385.	4954.	21414.	8180.	81288.	3725.	24343.	22929.	8617.
MAR 83	2	BOSWTH	11185.	18712.	882.	11236.	96.	574.	549.	4108.	218.	1015.	374.	421.
MAR 83	3	BRIDGNTH	4249.	7136.	578.	4202.	91.	485.	2.	134.	9.	514.	145.	255.
MAR 83	4	BROMSGR	16321.	22822.	1809.	14532.	107.	694.	141.	3633.	112.	1576.	250.	474.
MAR 83	5	CANNOCK	12670.	21555.	1502.	12368.	334.	3146.	245.	6715.	113.	1506.	573.	562.
MAR 83	6	CONGLETN	8499.	11994.	591.	8136.	76.	723.	226.	4901.	104.	719.	271.	352.
MAR 83	7	COVENTRY	55728.	101349.	7013.	51572.	1190.	5089.	1281.	52742.	594.	5678.	7594.	2039.
MAR 83	8	DUDLEY	55500.	97980.	8886.	46740.	1480.	6854.	1876.	31163.	711.	5359.	3371.	2304.
MAR 83	9	E STAFFS	1849.	3144.	179.	1628.	46.	268.	17.	429.	16.	290.	81.	138.
MAR 83	10	HEREFORD	7159.	14018.	1046.	7457.	262.	1490.	158.	4834.	67.	1265.	652.	546.
MAR 83	11	LEOMSTER	1650.	3088.	232.	1642.	85.	383.	34.	91.	20.	271.	22.	173.
MAR 83	12	LICHFD	14021.	19507.	1721.	12265.	146.	1083.	120.	1535.	81.	1266.	687.	463.
MAR 83	13	MALV H	8772.	13732.	1167.	8322.	116.	871.	189.	96.	108.	1216.	2155.	556.
MAR 83	14	NEWCASTL	21620.	33345.	1513.	18716.	491.	3765.	253.	4088.	111.	2358.	3057.	897.
MAR 83	15	N SHROP	2637.	4227.	402.	2352.	58.	371.	19.	99.	13.	425.	169.	203.
MAR 83	16	N WARKS	5452.	8744.	587.	5208.	77.	543.	283.	1393.	120.	657.	154.	298.
MAR 83	17	NUNEATON	17145.	29639.	2838.	16832.	255.	1686.	478.	7152.	196.	1400.	1949.	638.
MAR 83	18	OSWESTRY	2608.	4538.	262.	2407.	65.	568.	67.	50.	13.	546.	219.	235.
MAR 83	19	REDDITCH	12795.	22023.	2146.	13439.	115.	618.	1043.	7464.	430.	1332.	519.	444.
MAR 83	20	RUGBY	13346.	21618.	1536.	12946.	287.	1049.	240.	2151.	83.	1318.	441.	569.
MAR 83	21	SANDWELL	46945.	95196.	10004.	37228.	1595.	10010.	2862.	50132.	1025.	5667.	3825.	2496.
MAR 83	22	SHREWSBY	10516.	18913.	1053.	11751.	184.	1461.	118.	682.	45.	1779.	1142.	623.
MAR 83	23	SOLIHULL	43928.	60264.	11108.	33055.	348.	1710.	329.	2194.	107.	3045.	3740.	951.
MAR 83	24	S HEREFS	198.	306.	19.	209.	1.	7.	0.	128.	0.	1.	0.	2.
MAR 83	25	S SHROPS	1638.	3007.	282.	1606.	66.	375.	44.	0.	17.	294.	96.	185.
MAR 83	26	S STAFFS	13303.	19423.	1502.	11973.	156.	873.	136.	3639.	33.	837.	566.	332.
MAR 83	27	STAFFORD	17516.	26983.	2379.	15339.	354.	1644.	220.	7153.	72.	2145.	4127.	761.
MAR 83	28	STAFFS M	13531.	20720.	1410.	11742.	172.	1695.	316.	9591.	145.	1271.	719.	546.
MAR 83	29	STOKE	41534.	73251.	3099.	39328.	1304.	9619.	1597.	73460.	646.	6447.	2927.	2556.
MAR 83	30	STRATFD	9611.	14095.	1055.	8818.	83.	508.	199.	622.	103.	1308.	1116.	518.
MAR 83	31	TAMWORTH	10792.	20368.	2057.	12339.	141.	907.	344.	2716.	148.	1168.	218.	392.
MAR 83	32	WALSALL	47420.	76991.	6518.	37622.	1525.	5718.	2518.	22899.	911.	4905.	3277.	1945.
MAR 83	33	WARWICK	21691.	34595.	2945.	20352.	290.	1408.	481.	9184.	224.	2724.	1956.	1131.
MAR 83	34	WOLV	43058.	77296.	9597.	34065.	1567.	6961.	1553.	32957.	634.	5933.	5680.	2018.
MAR 83	35	WORCS	11645.	22554.	1527.	11402.	345.	1763.	342.	4363.	160.	2307.	1258.	831.
MAR 83	36	WREKIN	18651.	35281.	4011.	21040.	478.	2501.	935.	9541.	222.	2063.	6475.	856.
MAR 83	37	WYCHAVON	4007.	6906.	1774.	3598.	75.	377.	156.	2287.	55.	576.	335.	166.
MAR 83	38	WYRE FOR	14233.	24729.	2295.	13044.	288.	1619.	175.	9158.	71.	1599.	328.	709.
MAR 83		TOTAL	821400.	1410455.	126800.	705900.	19300.	100886.	27729.	454771.	11463.	97125.	83375.	37201.
MAR 82	1	BHAM	180181.	320978.	28602.	120689.	5270.	19513.	10637.	88960.	3775.	25423.	23272.	8628.
MAR 82	2	BOSWTH	11735.	18251.	868.	10794.	114.	579.	751.	4479.	191.	1066.	381.	407.
MAR 82	3	BRIDGNTH	4365.	7040.	599.	3921.	107.	492.	14.	122.	11.	571.	109.	246.
MAR 82	4	BROMSGR	16722.	22493.	1877.	13725.	160.	678.	224.	4739.	89.	1518.	166.	467.
MAR 82	5	CANNOCK	12799.	21309.	1579.	11480.	371.	3138.	296.	7125.	108.	1423.	710.	557.
MAR 82	6	CONGLETN	8447.	11815.	638.	7674.	130.	816.	322.	5507.	108.	712.	257.	356.
MAR 82	7	COVENTRY	57995.	100720.	6933.	48857.	921.	4901.	1891.	51325.	577.	6140.	7206.	2033.
MAR 82	8	DUDLEY	55200.	97198.	8853.	43308.	1342.	6540.	2337.	38054.	706.	5522.	2799.	2319.
MAR 82	9	E STAFFS	1736.	3064.	182.	1496.	26.	282.	16.	158.	16.	269.	0.	136.

Table B1 Sources of information on emissions.

The following sources of information are available from Dudley Metropolitan Borough Council for the Blackbrook Valley

1. Monthly computer printout of addresses and Land Use Classification codes for all premises in the Enterprise Zone.

2. The above information for named streets outside the Enterprise Zone.

3. Accompanying large scale (6") O.S. maps for the areas defined above.

4. Maps of Dudley and surrounding areas (scale 1:15000)

5. Population Census Data and accompanying ward maps.

6. Annual Survey data for industrial premises in the Enterprise Zone. Includes information on fuels used, potential or actual emission sources, area of property, storage of fuel and hazardous materials.

7. Pollution audit for Round Oak Steel Works.*

Note
* Round Oak Steel Works (ROSW), formerly the largest polluter in the Blackbrook Valley area, was closed in December 1982. Shortly before this date the author conducted an interview with Mr W Montgomery, when the pollution audit and some additional documents concerning ROSW were made available for the present study. This material has been passed to Dudley Council (Environmental Health Department).

APPENDIX C

Mossbag Survey of Dudley Borough

NB. Certain limitations in these data (eg. p.231, p.239) are due in large part to circumstances beyond the researcher's control.

APPENDIX C Mossbag Survey of Dudley Borough

Background to mossbag survey and sample analysis.

Dudley Metroplitan Borough Council (Pollution Division) carried out a mossbag survey of the borough of Dudley in September of 1978 or 1979. Details of the method used are described by Muskett.[1] The mossbags consisted of small (1-2 gm) balls of sphagnum moss tied in hairnet bags and suspended from bamboo poles. The mossbags were located at about 120 sampling sites identified according to the 1 km grid, O.S. map sheet 139 (section SO). The actual location of the sampling sites depended on the availability of suitable areas. Where possible private gardens were used. The mossbags were exposed for 38 days, then collected and sent to Birmingham Scientific Laboratory where they were acid-digested and analysed for metals lead, copper, iron, zinc, nickel, manganese, cadmium and chromium. Levels of the last two elements were insignificant and so this data was not made available to Dudley. The results for the other elements are shown in Table C6.

Following the launch of the IHD project, it was decided that data from a second mossbag survey would provide a useful historical comparison of metal levels for the area. Dudley Council agreed to run another survey on the understanding that the finance/resources for the sample analysis would be provided by Aston University.

The second mossbag survey was carried out in September 1983. The experimental method, source of the test material (moss) and sampling sites were the same as in the original survey. Following completion of the survey, the mossbags were collected and brought to Aston University for analysis. The samples were acid-digested in November/December 1983. They were analysed by a Perkin Elmer Atomic Absorption

Spectrophotometer (AAS) in the period January to August 1984. During this time there were recurrent problems, both with mechanical failure of equipment and with the calibration of samples and standard solutions. The results obtained are shown in Table C7. The reliability of these is uncertain. The use of Analar grade nitric acid in the preparation of samples means that these were probably contaminated with traces of various metals. During analysis for copper it was also discovered that the copper content of the de-ionised water supply gave readings of the same order as the moss samples. The remaining analyses for copper and nickel were abandoned.

In addition to the main survey a control experiment was undertaken. The purpose of this was a) to enable comparison of results obtained by different laboratories, and b) to examine the reproducibility of samples. For this, 25 mossbags were suspended at the same height in a $0.5m^2$ grid arrangement on the Second Floor balcony of the Main Building at Aston. The mossbags were exposed for a similar period to the main survey. The 25 bags were then collected and divided into three batches for independent analysis by three different laboratories. These were:

Aston University, Birmingham (25 samples)
Birmingham Scientific Laboratory (5 samples)
New Era Laboratory, London (5 samples)

Due to the difficulties already described, the Aston samples were not analysed. The procedures used by the other laboratories and results obtained are in Tables C1 to C3, and C4 to C5 respectively.

Table C1 Mossbag analysis: summary of procedure used at Aston University.

The method was based on that described by Crump.(2)

1. Moss was removed from net bags and placed in a pre-weighed 100ml conical flasks. Samples were then dried in an oven to constant weight (approx. 24 hours at 45 degrees centigrade).

2. After drying, flasks plus contents were reweighed to obtain dry weight of moss samples.

3. Samples were then digested with 10 ml of concentrated nitric acid (Analar grade), the flasks being simmered on a hot plate for approximately 30 minutes.

4. After allowing to cool, each sample was diluted and made up to 25 ml with de-ionised water[1].

5. Samples were transferred to glass (Macartney) bottles and stored in a refridgerator.

6. Solutions were analysed by AAS for for elements:

   Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn

Note [1] Aston control samples were first diluted with de-ionised water and filtered using Whatman No. 1 paper.

Table C2 Mossbag analysis: summary of procedure used by Birmingham Scientific Laboratory.

1. Moss was removed from net bags and placed in pre-weighed silica dishes.

2. Samples were dried to constant weight at 100 degrees Centigrade. Approximately 2 hours was found to be sufficient.

3. Moss residue was then treated with 2 ml hydrochloric acid (S.G. 1.16) and heated to dryness on a steam bath.

4. Then 8ml (3M) HCl was added, the dish covered and allowed to stand for a further 30 minutes on the steam bath.

5. Contents of each dish was filtered through a Whatman 41 filter paper and diluted with de-ionised water to 25ml.

6. Resulting solutions were analysed by AAS for metals:

   Cd, Cr, Cu, Mn, Ni, Pb, Zn.

   Results were expressed as mg metal per kg dried moss.

Note In a comparison test carried out with Nitric acid, only iron (Fe) gave a significantly different (lower) result than with HCl.

Table C3 Mossbag analysis: summary of procedure used by New Era Laboratory

1. Samples were oven dried for 24 hours at 100 degrees Centigrade.

2. Moss was transferred to conical flasks. Samples were then treated with 3 ml concentrated sulphuric acid and the flasks placed on a hot plate (60-70 °C) for 30 minutes.

3. After allowing to cool the residue was oxidised with concentrated hydrogen peroxide, and the flasks returned to the hot plate for a further 16 minutes.

4. Samples then made up to 10 ml with distilled water.

5. AAS analysis was carried out using IPC Photospectrometer, for standard 22 elements including

   Cd, Cr, Cu, Mn, Ni, Pb, Zn.

6. Computer printout of results given as mg metal per kg wet weight.

Table C4 Mossbag survey (Aston controls): summary of metal analysis results (mg/kg dry wt) obtained by Birmingham Scientific Laboratory.

Metal	Moss sample 1	2	3	4	5	mean
Pb	55	-	-	30	35	40
Cu	50	-	-	35	35	40
Zn	140	-	-	90	110	113
Fe	550	-	-	340	380	423
Ni	25	-	-	17	19	20
Mn	16	-	-	10	11	12

Notes - indicates no data (samples lost during analysis)

Table C5 Mossbag survey (Aston controls): summary of metal analysis results (mg/kg dry wt) obtained by New Era Laboratory.

Metal	Moss sample Blank	A	B	C	D	E
Al	65.46	145.36 (79.9)	256.16 (190.70)	267.82 (202.36)	212.87 (147.41)	236.03 (170.57)
Cd	* 0.48	* 0.46 (N.D.)	* 0.48 (N.D.)	* 0.52 (N.D.)	* 0.62 (N.D.)	* 0.49 (N.D.)
Cr	* 1.11	3.02 (1.68)	6.21 (4.87)	7.28 (5.94)	6.76 (5.42)	4.79 (3.45)
Cu	3.44	18.79 (15.35)	53.58 (50.98)	40.87 (37.43)	29.35 (25.91)	36.96 (33.52)
Fe	77.34	330.99 (253.65)	531.25 (453.91)	565.48 (488.14)	414.51 (337.17)	459.57 (382.23)
Mn	0.48	8.13 (7.65)	13.10 (12.62)	12.56 (12.08)	10.46 (9.98)	8.54 (8.06)
Ni	* 1.46	12.94 (11.48)	21.05 (19.59)	21.42 (19.96)	19.75 (18.29)	15.93 (14.47)
Pb	* 9.68	35.01 (25.33)	34.07 (24.39)	38.27 (28.59)	20.14 (10.46)	31.35 (21.67)
Zn	32.64	91.24 (58.6)	171.36 (138.72)	176.12 (143.48)	110.77 (78.13)	129.30 (76.23)

Note
* below level of detection
( ) corrected for blank i.e. accumulated metal content
N.D. not detectable i.e. same as blank

Table C6 Moss bag survey 1978/79: results

Site no.	Map ref.[1]	Heavy Metal Contents (ppm/day) Lead	Copper	Zinc	Nickel	Iron	Manganese
1	91/95	0.57	1.72	4.42	0.12	5.89	0.12
2	92/95	1.10	1.33	3.37	0.35	108.26	4.41
3	94/95	0.84	1.98	2.97	0.17	14.32	0.47
4	95/95	0.97	1.98	5.47	0.14	11.42	0.60
5	91/94	0.57	2.11	4.42	0.09	4.31	0.10
6	92/94	0.84	1.72	7.26	0.12	13.00	0.23
7	93/94	0.57	1.85	7.26	0.12	6.95	0.18
8	94/94	0.71	1.85	4.95	0.17	6.95	0.23
9	95/94	0.57	1.59	4.68	0.14	9.05	0.36
10	91/93	0.71	1.85	7.26	0.09	3.79	0.15
11	92/93	0.57	2.25	2.84	0.17	8.26	0.23
12	93/93	1.10	1.72	2.32	0.12	5.63	0.20
13	94/93	0.71	1.59	2.58	0.19	7.47	0.26
14	95/93	0.71	1.98	4.42	0.19	21.42	0.73
15	90/92	0.57	1.72	4.68	0.14	4.84	0.18
16	91/92	0.57	1.85	6.00	0.12	8.00	0.15
17	92/92	0.57	2.91	4.68	0.41	22.74	0.73
18	93/92	0.71	1.72	6.26	0.19	6.42	0.39
19	94/92	0.71	1.59	6.79	0.12	6.42	0.39
20	95/92	0.57	1.85	2.18	0.14	6.42	0.26
21	90/91	0.57	1.59	2.32	0.12	0.63	0.12
22	91/91	0.57	1.72	2.05	0.27	6.16	0.26
23	92/91	1.23	1.72	3.63	0.25	28.00	0.86
24	93/91	0.84	1.72	3.37	0.33	6.68	0.31
25	94/91	1.36	1.72	6.00	0.09	0.37	0.47
26	95/91	1.23	2.64	4.16	0.19	14.58	0.60
27	96/91	1.23	2.11	5.74	0.27	12.47	0.41
28	87/90	0.44	2.11	2.18	0.17	5.63	0.12
29	88/90	0.71	1.72	4.16	0.12	3.53	0.12
30	89/90	0.71	1.59	2.58	0.17	4.58	0.23
31	90/90	–	–	–	–	–	–
32	91/90	0.97	2.12	3.11	0.22	15.63	0.36
33	92/90	1.10	1.72	3.11	0.17	8.79	0.36
34	93/90	0.84	1.72	2.58	0.14	8.26	0.41
35	94/90	1.10	1.72	4.42	0.17	9.58	0.44
36	95/90	2.28	1.85	6.79	0.12	–	0.60
37	96/90	0.97	1.85	3.37	0.14	9.58	0.36
38	87/89	0.71	1.85	2.84	0.19	4.58	0.12
39	88/89	0.57	1.72	1.53	0.12	2.47	0.10
40	89/89	–	–	–	–	–	–
41	90/89	0.71	1.98	2.58	0.17	8.79	0.23
42	91/89	1.10	1.98	2.32	0.09	8.26	0.33
43	92/89	0.84	1.72	2.58	0.17	10.89	0.39
44	93/89	0.71	1.98	2.84	0.14	8.26	0.47
45	94/89	2.55	2.25	5.21	0.25	43.79	1.26
46	95/89	0.84	1.72	3.11	0.09	1.95	0.36
47	96/89	0.71	1.85	2.32	0.14	7.47	0.28
48	88/88	0.57	1.85	2.05	0.19	4.58	0.10
49	89/88	0.84	1.72	1.66	0.14	5.11	0.26
50	90/88	0.71	1.85	1.92	0.12	1.95	0.12

Table C6 cont.

Site no.	Map ref.[1]	Lead	Copper	Zinc	Nickel	Iron	Manganese
		Heavy Metal Contents (ppm/day)					
51	91/88	0.84	1.85	2.32	0.14	6.68	0.23
52	92/88	1.10	1.72	3.63	0.17	10.89	0.62
53	93/88	1.63	1.98	6.00	0.19	44.05	3.10
54	94/88	0.84	1.72	2.32	0.12	4.58	0.44
55	95/88	0.84	1.85	1.92	0.38	10.63	0.28
56	88/87	–	–	–	–	–	–
57	89/87	0.71	1.72	2.05	0.09	5.11	0.18
58	90/87	0.97	1.72	1.79	0.09	6.68	0.26
59	91/87	0.28	1.46	1.92	0.12	6.95	0.28
60	92/87	0.34	1.85	2.84	0.14	14.58	0.47
61	93/87	0.34	1.85	2.32	0.48	4.84	0.31
62	94/87	0.21	1.72	3.11	0.06	–	0.33
63	95/87	0.28	1.59	1.53	0.12	4.32	0.33
64	89/86	0.17	1.68	8.34	0.12	2.22	0.32
65	90/86	0.26	2.32	10.86	0.41	25.00	0.09
66	91/86	0.15	1.68	2.34	0.18	14.02	0.11
67	92/86	0.12	2.06	14.02	0.41	10.89	0.08
68	93/86	0.65	1.42	5.18	0.18	5.14	0.14
69	94/86	0.42	1.93	2.34	0.12	4.56	0.09
70	97/86	1.07	2.95	5.49	0.18	15.95	0.16
71	98/86	0.65	1.93	3.28	0.06	5.73	0.09
72	99/86	–	–	–	–	–	–
73	88/85	0.48	1.68	2.97	0.06	1.93	0.08
74	89/85	0.51	2.06	4.23	0.18	5.43	0.17
75	90/85	1.31	2.46	5.60	0.50	10.24*	0.28
76	91/85	0.79	1.55	2.94	0.12	3.39	0.08
77	92/85	0.37	1.55	2.94	0.12	3.97	0.10
78	93/85	0.26	1.04	2.65	0.18	4.27	0.08
79	94/85	0.48	1.68	2.02	0.18	9.52	0.12
80	95/85	0.34	1.55	2.34	0.41	4.56	0.01
81	96/85	0.51	2.32	2.97	0.53	8.65	0.06
82	97/85	0.20	2.46	1.71	0.30	2.51	0.02
83	98/85	0.65	4.23	3.92	0.41	–	0.10
84	99/85	0.17	0.65	0.76	0.06	35.23	0.01
85	88/84	0.65*	1.68	10.23	0.30	8.06	0.04
86	89/94	0.65*	1.55	3.60	0.12	4.27	0.09
87	90/84	–	–	–	–	–	–
88	91/84	0.37	1.29	2.34	0.12	8.65	0.09
89	92/84	0.26	1.42	1.39	0.12	2.51	0.04
90	93/84	0.37	1.42	3.60	0.06	2.80	0.06
91	94/84	0.51	1.80	2.65	0.12	3.97	0.08
92	95/84	0.40	1.80	3.28	0.06	4.56	0.08
93	96/84	0.65	1.55	3.92	0.18	6.31	0.10
94	97/84	0.65	1.80	3.28	0.18	6.31*	0.08
95	98/84	0.23*	1.42	2.65	0.12	1.64	0.03
96	99/84	–	–	–	–	–	–
97	88/83	0.15*	2.32	1.39	0.12	1.64	0.03
98	89/83	0.65	2.06	2.34	0.18	5.43	0.09
99	90/83	0.17	1.42	2.65	0.06	–	0.03
100	91/83	0.15*	1.68	2.02	0.06	–	0.07

Table C6 cont.

Site no.	Map ref.[1]	Lead	Copper	Zinc	Nickel	Iron	Manganese
		Heavy Metal Contents (ppm/day)					
101	92/83	0.23*	1.68	2.02	0.06	0.18	0.04
102	93/83	-	-	-	-	-	-
103	94/83	0.51	2.46	2.94	0.18	5.43	0.18
104	95/83	0.42	1.55	2.94	0.12	3.68	0.10
105	96/83	0.48	1.29	2.65	0.06	1.05	0.08
106	97/83	0.12	0.91	1.39	0.06	-	0.02
107	98/83	0.65	1.68	3.92	0.12	2.80	0.09
108	99/83	0.51	1.42	3.28	0.06	1.34	0.04
109	89/92	0.37	1.55	1.71	0.12	-	0.08
110	90/82	0.37	1.29	2.02	0.06	0.76	0.06
111	91/82	0.65	13.83	7.07	0.24	4.85	0.04
112	92/82	0.26	2.32	2.65	0.18	3.97	0.09
113	94/82	0.51	1.80	2.97	0.24	73.20	0.94
114	95/82	1.35	1.93	3.92	0.12	4.85	0.15
115	96/82	-	-	-	-	-	-
116	97/82	0.42	1.68	2.97	0.06	2.80	0.10
117	98/82	0.40	1.93	4.23	0.18	10.24*	0.17
118	99/82	-	-	-	-	-	-
119	89/81	0.40	1.55	1.39	0.12	-	0.04
120	90/81	0.26	1.42	2.34	0.18	-	0.03
121	91/81	0.31	1.04	7.07	0.12	3.10	-
122	96/81	-	-	-	-	-	-
123	98/81	-	-	-	-	-	-

Notes [1] Map reference O.S. Sheet 139 (Section SO)
- missing data
* data may be incorrect, see details below.

According to Dudley Council the samples had been analysed in two batches. A slight differences in results was found between these batches, possibly due to differences in cleaning processes. A correction factor was applied to enable comparison of data sets. The above table shows only the corrected figures. Examination of the data supplied by Dudley had identified a number of mismatches between corrected and uncorrected values, suggesting that there were transcribing or calculation errors in the data. The original raw data was not available to verify this. Suspect values are therefore indicated in the above table by an asterix.

Table C7 Mossbag Survey 1983: Aston analysis results

Site no.	Map ref.[1]	Daily deposition metal (ppm) Lead	Cadmium	Zinc	Iron	Manganese
1	91/95	0.32	<0.01	5.08	4.78	0.07
2	92/95	0.74	0.02	9.93	5.64	0.25
3	94/95	0.46	0.01	9.70	7.00	0.33
4	95/95	0.39	0.01	9.06	3.65	0.15
5	91/95	0.29	N.D.	5.00	3.77	0.09
6	92/94	0.44	0.01	8.16	2.16	0.24
7	93/94	0.53	<0.01	8.50	7.33	0.23
8	94/94	1.02	0.01	8.56	6.81	0.24
9	95/94	0.59	<0.01	9.59	3.05	0.18
10	91/93	0.16	<0.01	5.20	7.19	0.12
11	92/93	0.19	<0.01	3.71	1.71	0.09
12	93/93	0.21	<0.01	5.45	1.76	0.15
13	94/93	0.28	0.01	17.53	3.02	0.27
14	95/93					
15	90/92	0.37	<0.01	13.17	5.99	0.24
16	91/92	0.45	0.01	15.71	4.75	0.27
17	92/92	0.28	0.01	19.14	5.69	0.21
18	93/92	0.28	0.01	10.06	7.82	0.18
19	94/92	0.27	0.01	10.45	6.96	0.22
20	95/92	0.56	0.01	17.08	8.18	0.42
21	90/91	0.56	0.01	21.07	7.53	2.34
22*	91/91					
23	92/91	0.42	0.01	16.18	6.52	0.24
24*	93/91					
25	94/91	0.39	0.01	14.68	4.38	0.41
26	95/91	0.49	0.02	40.98	7.31	1.14
27	96/91	0.76	0.02	26.43	8.31	1.47
28	87/90	0.08	0.01	6.08	2.45	0.07
29	88/90	0.40	<0.01	5.59	3.00	0.07
30	89/90	0.19	0.01	10.05	3.96	0.29
31	90/90	0.62	<0.01	23.33	3.78	0.48
32	91/90	0.25	0.01	12.52	2.70	0.25
33*	92/90					
34	93/90	0.32	0.01	15.13	3.28	0.83
35	94/90	0.29	0.01	14.51	3.12	0.37
36	95/90	0.55	0.03	26.99	8.77	1.21
37	96/90	0.46	0.01	13.28	3.12	0.36
38	87/89	0.17	N.D.	6.81	3.88	0.16
39	88/89	0.16	N.D.	8.79	0.74	0.14
40	89/89	0.56	<0.01	12.38	0.97	0.15
41	90/89	0.29	<0.01	8.40	3.38	0.14
42	91/89	90.29	–	14.41	4.78	0.40
43	92/89	0.04	<0.01	–	–	N.D.
44	93/89	0.42	0.01	19.13	2.87	0.26
45*	94/89					
46	95/89	0.34	0.02	15.22	6.83	0.41
47	96/89	0.35	0.01	18.19	3.71	0.24
48	88/88	0.06	0.01	4.36	1.87	0.04
49	89/88	0.46	0.01	13.65	4.60	0.20
50	90/88	0.29	0.02	12.90	3.12	0.25

Table C7 cont.

Site no.	Map ref.[1]	Daily deposition metal (ppm) Lead	Cadmium	Zinc	Iron	Manganese
51	91/88	0.43	0.01	13.30	5.78	0.23
52	92/88	0.38	0.01	10.78	8.65	0.21
53	93/88	0.55	0.01	27.65	6.00	0.57
54	94/88	0.15	0.01	9.92	4.45	0.10
55	95/88	0.20	<0.01	12.62	4.29	0.14
56	88/87	0.28	0.01	7.81	4.51	0.04
57	89/87	0.09	0.01	8.99	5.42	0.14
58*	90/87					
59	91/87	0.87	0.01	8.48	2.19	0.16
60	92/87	0.43	0.01	21.59	11.09	0.52
61	93/87	0.51	0.01	16.41	3.11	0.27
62	94/87	0.20	<0.01	11.13	6.67	0.11
63	95/87	0.30	-	12.00	4.75	0.20
64	89/86	0.24	0.01	10.59	2.99	0.11
65	90/86	0.60	N.D.	8.85	7.49	0.10
66*	91/86					
67	92/86	0.18	<0.01	8.66	3.06	0.12
68	93/86	0.28	N.D.	8.61	1.89	0.11
69	94/86	0.24	N.D.	11.80	6.30	0.06
70	97/86	0.45	0.01	11.26	3.13	0.24
71	98/86	0.28	N.D.	7.35	6.20	0.18
72	99/86	0.43	<0.01	12.48	5.06	0.29
73	88/85	0.28	<0.01	4.57	1.80	0.09
74	89/85	0.28	<0.01	4.97	3.25	0.09
75	90/85	0.37	0.01	8.62	3.44	0.10
76	91/85	0.24	0.01	5.92	2.55	0.20
77	92/85	0.17	0.01	4.13	3.21	0.02
78	93/85	0.52	<0.01	9.96	4.7	0.01
79	94/85	0.26	N.D.	8.47	5.44	0.42
80	95/85	0.21	<0.01	7.43	4.13	0.33
81	96/85	0.46	0.01	10.34	4.67	0.25
82	97/85	0.72	0.01	65.10	9.06	1.22
83	98/85	0.22	N.D.	4.65	5.00	0.11
84*	99/85					
85	88/84	0.23	0.01	7.55	5.54	0.21
86	89/84	0.26	<0.01	4.16	4.26	0.12
87	90/84	0.29	<0.01	6.41	5.00	0.10
88	91/84	0.26	<0.01	10.49	5.71	0.15
89	92/84	0.35	0.01	7.19	7.71	0.07
90	93/84	0.29	N.D.	7.67	7.14	0.21
91	94/84	0.36	N.D.	9.90	3.93	0.18
92	95/84	0.20	<0.01	4.59	3.56	0.05
93*	96/84					
94	97/84	0.22	<0.01	12.53	2.08	0.19
95	98/84	0.34	<0.01	6.82	6.91	0.07
96	99/84	0.33	0.01	4.51	3.26	0.06
97	88/83	0.17	<0.01	2.96	0.96	0.08
98	89/83	0.11	<0.01	2.03	1.49	0.02
99	90/83	0.26	<0.01	4.65	1.03	0.08
100	91/83	0.18	-	2.64	1.48	0.04

Table C7 cont

Site no.	Map ref.[1]	Daily deposition metal (ppm) Lead	Cadmium	Zinc	Iron	Manganese
101	92/83	0.10	0.01	2.54	2.01	>0.01
102	93/83	0.16	N.D.	2.92	1.37	0.11
103	94/83	0.17	<0.01	5.52	1.78	0.15
104	95/83	0.57	<0.01	4.42	1.60	0.02
105	96/83	0.35	N.D.	5.62	1.74	0.09
106	97/83	0.28	<0.01	5.61	2.49	0.13
107	98/83	0.75	<0.01	9.78	4.20	0.06
108*	99/83					
109*	89/82					
110	90/82	0.14	<0.01	4.07	2.90	0.04
111	91/82	0.10	0.01	2.46	1.77	-
112	92/82	0.34	N.D.	6.85	4.11	0.15
113	94/82	0.46	0.01	5.86	3.86	0.10
114	95/82	0.82	N.D.	16.12	0.91	0.12
115	96/82	0.37	<0.01	8.11	4.34	0.18
116*	97/82					
117	98/82	0.31	0.01	12.04	2.67	0.28
118	99/82	0.40	0.01	6.93	4.75	0.28
119*	89/81					
120	90/81	0.17	<0.01	6.29	3.89	0.11
121	91/81	0.45	<0.01	10.41	2.93	0.34
122	96/81	0.47	0.01	7.81	4.42	0.34
123	98/81	0.53	<0.01	6.56	2.42	0.09

Notes
[1] O.S. Map sheet 139 (Section SO)
* missing sample
\- missing data
N.D. not detectable

APPENDIX D

Lichen Board Survey Data

Fig. D1 Lichen Board Survey 1: sample score sheet for recording photographic data

LICHEN BOARD NO.

20.12.83	1	2	3	4	5	6	7	8	9	10	
% gn											
% wh											
% bwn											
% lost											

10.1.84	1	2	3	4	5	6	7	8	9	10	
% gn											
% wh											
% bwn											
% lost											

21.2.84	1	2.	3	4	5	6	7	8	9	10.	
% gn											
% wh											
% bwn											
% lost											

20.3.84	1	2	3	4	5	6	7	8	9	10	
% gn											
% wh											
% bwn											
% lost											

3.4.84	1	2	3	4	5	6	7	8	9	10	
% gn											
% wh											
% bwn											
% lost											

18.4.84	1	2	3	4	5	6	7	8	9	10.	
% gn											
% wh.											
% bwn											
% lost											

2.5.84	1	2	3	4	5	6	7	8	9	10	
% gn											
% wh											
% bwn											
% lost											

12.6.84	1	2	3	4	5	6	7	8	9	10	
% gn											
% wh											
% bwn											
% lost.											

Table D1 Lichen Board Survey 1: summarised data for boards and weeks.

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MTB > TABLE C1 C2;
MTB > MEAN C5;
MTB > STDEV C5;
MTB > NONMISSING C5.
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ROWS: C1 COLUMNS: C2

	0	3	9	13	15	17	19	25
1	99.000	99.000	94.250	91.500	89.000	--	89.000	--
	3.162	3.162	6.672	7.091	6.992	--	6.992	--
	10	10	10	10	10	0	10	0
2	98.500	96.000	92.500	82.000	78.500	77.000	77.500	64.000
	2.415	5.164	8.580	8.882	9.733	9.775	8.580	11.005
	10	10	10	10	10	10	10	10
3	97.500	94.500	92.000	89.500	88.000	82.000	84.500	78.500
	4.249	7.976	7.149	8.317	9.189	16.193	13.427	16.675
	10	10	10	10	10	10	10	10
4	95.500	95.000	94.000	91.500	79.000	76.500	77.500	67.500
	3.689	3.333	3.944	4.116	7.746	7.835	8.580	7.546
	10	10	10	10	10	10	10	10
5	97.500	98.000	96.000	87.500	70.000	67.000	70.500	44.000
	2.635	2.582	3.944	4.249	17.321	17.826	18.174	14.491
	10	10	10	10	10	10	10	10
6	96.000	93.000	92.500	91.500	89.750	88.000	90.250	86.250
	7.746	10.593	10.341	8.835	8.776	9.339	7.768	10.155
	10	10	10	10	10	10	10	10
7	99.000	97.750	96.750	94.000	86.000	82.000	84.500	66.000
	2.108	2.189	3.129	5.164	8.182	10.193	7.976	27.467
	10	10	10	10	10	10	10	10
8	98.500	95.250	83.000	74.500	62.000	59.000	68.000	54.000
	2.415	2.189	6.214	11.655	11.353	11.499	8.563	13.292
	10	10	10	10	10	10	10	10
9	93.500	89.750	86.750	80.750	77.500	69.500	74.500	69.000
	7.472	7.857	9.358	10.740	8.250	10.659	9.265	12.202
	10	10	10	10	10	10	10	10
10	94.500	93.000	90.500	87.500	85.000	82.250	86.500	73.000
	7.619	4.830	7.619	11.607	10.475	10.169	11.377	11.106
	10	10	10	10	10	10	10	10
11	94.000	86.000	86.500	87.000	76.500	75.500	85.500	75.000
	8.097	6.992	7.835	7.528	9.733	9.265	7.246	10.274
	10	10	10	10	10	10	10	10
12	89.000	83.000	84.000	78.000	73.000	71.500	78.500	66.500
	11.738	12.293	9.068	3.496	8.233	7.835	7.091	10.554
	10	10	10	10	10	10	10	10

Table D1 cont.

	0	3	9	13	15	17	19	25
13	98.500	93.000	87.000	80.500	73.000	71.500	80.500	66.500
	3.375	5.869	11.106	8.960	12.065	11.559	7.619	20.956
	10	10	10	10	10	10	10	10
14	92.500	94.500	89.500	82.500	82.000	77.500	81.500	70.000
	9.204	7.246	8.644	7.906	8.563	8.898	7.091	9.129
	10	10	10	10	10	10	10	10
15	98.500	88.000	87.500	83.500	74.500	71.000	79.000	66.500
	2.415	6.749	6.346	10.014	13.427	14.682	15.055	15.284
	10	10	10	10	10	10	10	10
16	99.000	85.000	86.000	88.000	74.500	72.000	86.000	57.000
	3.162	8.819	8.097	4.216	6.433	5.869	3.162	10.853
	10	10	10	10	10	10	10	10
18	95.000	94.000	85.500	80.000	74.500	74.500	82.000	67.000
	7.071	6.992	7.246	9.718	9.846	8.644	6.749	19.465
	10	10	10	10	10	10	10	10
19	100.000	91.000	88.500	87.000	71.000	70.000	76.000	52.000
	0.000	6.146	3.375	4.216	11.499	12.247	11.499	17.192
	10	10	10	10	10	10	10	10
20	97.000	96.000	94.000	88.250	83.750	79.500	90.500	79.500
	4.216	5.164	6.146	10.544	11.134	10.124	8.882	10.124
	10	10	10	10	10	10	10	10
21	99.000	98.500	97.500	93.000	88.500	84.000	91.000	78.500
	2.108	2.415	3.333	5.869	4.743	6.583	3.162	4.743
	10	10	10	10	10	10	10	10
23	98.500	94.000	93.250	87.500	83.750	84.000	87.250	79.000
	3.375	6.146	7.910	11.547	12.318	12.202	8.855	13.292
	10	10	10	10	10	10	10	10
24	100.000	95.750	77.250	81.000	72.250	70.500	79.500	65.000
	0.000	5.007	12.826	16.296	19.381	16.741	14.230	17.951
	10	10	10	10	10	10	10	10
25	99.250	89.500	91.500	87.500	72.500	72.000	80.750	65.000
	1.687	4.378	4.116	4.859	3.536	6.749	5.007	6.236
	10	10	10	10	10	10	10	10
26	98.750	96.250	91.750	91.000	89.000	84.750	87.750	76.500
	3.173	3.773	3.736	3.764	4.282	6.175	6.713	7.835
	10	10	10	10	10	10	10	10
27	97.750	96.250	93.250	95.250	91.500	87.750	94.000	87.750
	3.217	3.953	8.337	4.480	7.746	8.371	5.553	9.461
	10	10	10	10	10	10	10	10
28	95.750	89.000	88.750	87.500	76.000	71.000	76.250	59.500
	4.721	6.146	7.193	8.975	8.515	11.559	10.086	14.424
	10	10	10	10	10	10	10	10
ALL	97.000	93.115	90.000	86.452	79.269	76.010	82.260	68.540
	5.522	7.247	8.460	9.540	12.255	12.505	11.020	16.637
	260	260	260	260	260	250	260	250

Table D2 Lichen Board Survey 1: summarised data for boards and weeks, excluding replicates with greater than 50% material lost.

```
MTB > TABLE C1 C2;
MTB > MEAN C5;
MTB > STDEV C5;
MTB > NONMISSING C5.
```

ROWS: C1 COLUMNS: C2

	0	3	9	13	15	17	19	25
1	99.000	99.000	94.250	91.500	89.000	--	89.000	--
	3.162	3.162	6.672	7.091	6.992	--	6.992	--
	10	10	10	10	10	0	10	0
2	98.500	96.000	92.500	82.000	78.500	77.000	77.500	64.000
	2.415	5.164	8.580	8.882	9.733	9.775	8.580	11.005
	10	10	10	10	10	10	10	10
3	97.500	94.500	92.000	89.500	88.000	82.000	84.500	78.500
	4.249	7.976	7.149	8.317	9.189	16.193	13.427	16.675
	10	10	10	10	10	10	10	10
4	95.500	95.000	94.000	91.500	79.000	76.500	77.500	67.500
	3.689	3.333	3.944	4.116	7.746	7.835	8.580	7.546
	10	10	10	10	10	10	10	10
5	97.500	98.000	96.000	87.500	70.000	67.000	70.500	44.000
	2.635	2.582	3.944	4.249	17.321	17.826	18.174	14.491
	10	10	10	10	10	10	10	10
6	96.000	93.000	92.500	91.500	89.750	88.000	90.250	86.250
	7.746	10.593	10.341	8.835	8.776	9.339	7.768	10.155
	10	10	10	10	10	10	10	10
7	99.000	97.750	96.750	94.000	86.000	82.000	84.500	73.333
	2.108	2.189	3.129	5.164	8.182	10.193	7.976	15.612
	10	10	10	10	10	10	10	9
8	98.500	95.250	83.000	74.500	62.000	59.000	68.000	54.000
	2.415	2.189	6.214	11.655	11.353	11.499	8.563	13.292
	10	10	10	10	10	10	10	10
9	93.500	89.750	86.750	80.750	77.500	69.500	74.500	69.000
	7.472	7.857	9.358	10.740	8.250	10.659	9.265	12.202
	10	10	10	10	10	10	10	10
10	94.500	93.000	90.500	87.500	85.000	82.250	86.500	73.000
	7.619	4.830	7.619	11.607	10.475	10.169	11.377	11.106
	10	10	10	10	10	10	10	10
11	94.000	86.000	87.222	87.778	76.667	76.111	86.111	75.556
	8.097	6.992	7.949	7.546	10.308	9.610	7.407	10.737
	10	10	9	9	9	9	9	9
12	89.000	83.000	84.000	78.000	73.333	71.667	78.333	66.111
	11.738	12.293	9.068	3.496	8.660	8.292	7.500	11.118
	10	10	10	10	9	9	9	9

Table D2 cont

	0	3	9	13	15	17	19	25
13	98.500	93.000	87.000	81.667	73.333	72.222	80.556	70.625
	3.375	5.869	11.106	8.660	12.748	12.018	8.079	16.995
	10	10	10	9	9	9	9	8
14	92.500	94.500	89.500	82.500	82.000	77.500	81.500	70.000
	9.204	7.246	8.644	7.906	8.563	8.898	7.091	9.129
	10	10	10	10	10	10	10	10
15	98.500	88.000	87.500	86.111	78.333	74.444	83.333	69.444
	2.415	6.749	6.346	6.009	6.124	10.442	6.614	12.856
	10	10	10	9	9	9	9	9
16	99.000	85.000	86.000	88.000	74.500	72.000	86.000	57.000
	3.162	8.819	8.097	4.216	6.433	5.869	3.162	10.853
	10	10	10	10	10	10	10	10
18	95.000	94.000	85.500	80.000	74.500	74.500	82.000	67.000
	7.071	6.992	7.246	9.718	9.846	8.644	6.749	19.465
	10	10	10	10	10	10	10	10
19	100.000	91.000	88.500	87.000	71.000	70.000	76.000	52.000
	0.000	6.146	3.375	4.216	11.499	12.247	11.499	17.192
	10	10	10	10	10	10	10	10
20	97.000	96.000	94.000	88.250	83.750	79.500	90.500	79.500
	4.216	5.164	6.146	10.544	11.134	10.124	8.882	10.124
	10	10	10	10	10	10	10	10
21	99.000	98.500	97.500	93.000	88.500	84.000	91.000	78.500
	2.108	2.415	3.333	5.869	4.743	6.583	3.162	4.743
	10	10	10	10	10	10	10	10
23	98.500	94.000	93.250	87.500	83.750	84.000	87.250	79.000
	3.375	6.146	7.910	11.547	12.318	12.202	8.855	13.292
	10	10	10	10	10	10	10	10
24	100.000	95.750	77.250	81.000	72.250	70.500	79.500	65.000
	0.000	5.007	12.826	16.296	19.381	16.741	14.230	17.951
	10	10	10	10	10	10	10	10
25	99.250	89.500	91.500	87.500	72.500	72.000	80.750	65.000
	1.687	4.378	4.116	4.859	3.536	6.749	5.007	6.236
	10	10	10	10	10	10	10	10
26	98.750	96.250	91.750	91.000	89.000	84.750	87.750	76.500
	3.173	3.773	3.736	3.764	4.282	6.175	6.713	7.835
	10	10	10	10	10	10	10	10
27	97.750	96.250	93.250	95.250	91.500	87.750	94.000	87.750
	3.217	3.953	8.337	4.480	7.746	8.371	5.553	9.461
	10	10	10	10	10	10	10	10
28	95.750	89.000	88.750	87.500	76.000	71.000	76.250	59.500
	4.721	6.146	7.193	8.975	8.515	11.559	10.086	14.424
	10	10	10	10	10	10	10	10
ALL	97.000	93.115	90.039	86.644	79.512	76.250	82.451	69.078
	5.522	7.247	8.453	9.385	12.070	12.361	10.782	15.895
	260	260	259	257	256	246	256	244

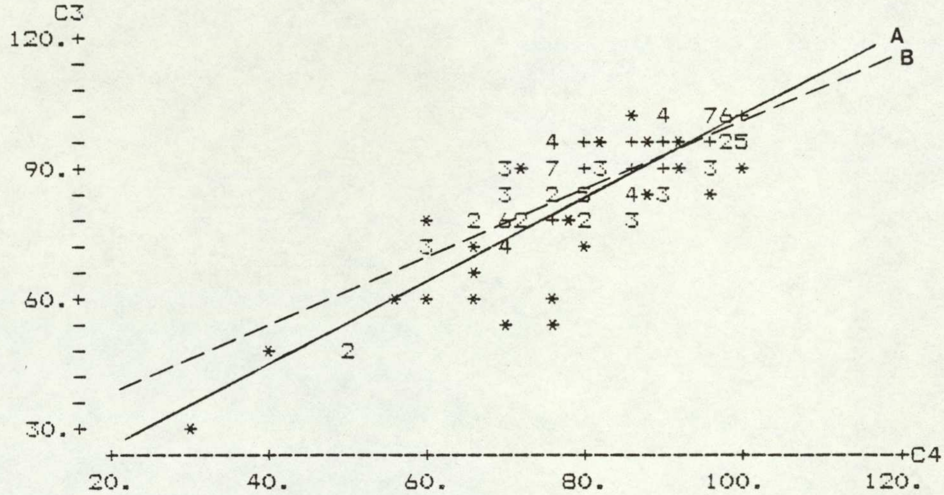
Table D3 Lichen Board Survey 1: test of reproducibility of scores.

In the test below 26 photographs were rescored. Score 1 is the "reproduced" score; score 2 is the original survey data.

COMPUTER PRINTOUT (MINTAB STATISTICAL PACKAGE)

A = expected regression line (r=1)
B = regression line of equation below

```
MTB >
MTB >
MTB >
MTB >£SCATTERPLOT OF SCORE 1 (C3) VS SCORE 2 (C4)
MTB >
MTB >
MTB >
MTB >PLOT C3 VS C4
```




```
MTB >
MTB >
MTB >
MTB >£REGRESSION ANALYSIS
MTB >
MTB >
MTB >REGRESS C3 1 C4,C5
```

THE REGRESSION EQUATION IS
C3 = 24.0 + 0.769 C4

COLUMN	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO = COEF/S.D.
	24.050	2.764	8.70
C4	0.76860	0.03214	23.91

S = 5.977

R-SQUARED = 68.9 PERCENT
R-SQUARED = 68.8 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

DUE TO	DF	SS	MS=SS/DF
REGRESSION	1	20431	20431
RESIDUAL	258	9218	36
TOTAL	259	29649	

Table D3 cont
(MINITAB PRINTOUT)

ROW	C4	Y C3	PRED. Y VALUE	ST.DEV. PRED. Y	RESIDUAL	ST.RES.
12	95	85.000	97.066	0.486	-12.066	-2.03R
16	80	70.000	85.537	0.407	-15.537	-2.61R
20	65	60.000	74.008	0.748	-14.008	-2.36R
68	70	90.000	77.851	0.614	12.149	2.04R
87	75	55.000	81.694	0.496	-26.694	-4.48R
117	70	55.000	77.851	0.614	-22.851	-3.84R
126	55	60.000	66.322	1.040	-6.322	-1.07 X
151	75	95.000	81.694	0.496	13.306	2.23R
156	75	95.000	81.694	0.496	13.306	2.23R
160	75	60.000	81.694	0.496	-21.694	-3.64R
161	40	50.000	54.793	1.500	-4.793	-0.83 X
169	70	90.000	77.851	0.614	12.149	2.04R
181	50	50.000	62.479	1.191	-12.479	-2.13RX
182	30	30.000	47.108	1.813	-17.108	-3.00RX
205	50	50.000	62.479	1.191	-12.479	-2.13RX
231	70	90.000	77.851	0.614	12.149	2.04R
233	75	95.000	81.694	0.496	13.306	2.23R
236	75	95.000	81.694	0.496	13.306	2.23R

R DENOTES AN OBS. WITH A LARGE ST. RES.
X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.

```
MTB >£CORRELATION OF SCORES
MTB >
MTB >
MTB >CORR C3 C4

   CORRELATION OF        C3 AND C4       = 0.830

MTB >
MTB >
MTB >
MTB >£TABLE OF DATA
MTB >
```

ROWS: C1

	C3 MEAN	C3 STD DEV	C4 MEAN	C4 STD DEV
1	86.50	4.74	83.000	6.214
2	85.50	11.65	88.250	10.544
3	98.00	2.58	98.500	2.415
4	94.00	2.11	88.000	4.216
5	92.75	5.06	88.500	3.375
6	91.00	5.16	87.750	6.713
7	91.50	4.74	82.500	7.906
8	90.50	5.50	90.500	7.619
9	88.50	12.26	92.000	7.149
10	87.50	8.25	80.000	7.817
11	98.50	3.37	99.000	2.108
12	89.50	12.79	89.500	8.317
13	75.50	8.64	67.500	7.546
14	99.00	2.11	95.750	4.721
15	92.00	3.50	92.000	3.496
16	88.18	11.02	76.364	6.360
17	83.33	17.32	71.667	15.612
18	82.25	8.70	76.000	8.515
19	76.50	21.22	76.500	21.220
20	93.50	6.58	89.500	4.378
21	76.00	13.70	76.000	13.703
22	93.50	4.12	82.000	6.749
23	85.00	6.24	76.500	7.835
24	94.00	3.16	81.500	7.091
25	95.50	2.84	88.000	6.749
26	100.00	0.00	98.750	3.173
ALL	89.56	10.70	85.231	11.556

Table D4 Lichen Board Survey 1: analysis of differences in final (week 25) mean % green scores in relation to % lost material.

Note Boards with no losses of material are not included.

Board	Mean %Green (all reps)	Mean %Green (reps >0% lost)	Reps	Range of %lost
1	89.00	89.44	1	45
2	64.00	67.50	6	10-25
5	44.00	48.33	7	5-40
7	66.00	75.70	3	10-99
8	54.00	54.44	1	5
9	69.00	68.00	5	5-45
10	73.00	76.25	2	30-50
11	75.00	72.86	3	25-75
12	66.10	67.86	2	5-10
13	70.60	76.60	5	20-50
14	70.00	70.00	2	15-25
15	66.00	68.88	1	75
24	65.00	60.00	4	10-30
25	65.00	64.44	1	30
26	77.00	76.39	1	5
27	87.75	88.75	1	25
28	59.50	61.11	1	20
mean x	68.29	69.80		
sum x	1160.95	1186.55		
sum x^2	81168.88	84648.33		
s.d.	10.86	10.70		

Table D5 Lichen Board Survey 1: Comparison of week 25 scores for bark-attached (+) and bark-free (-) discs.

Board	+ bark n	% green (a)	- bark n	% green (b)	all discs n	% green (c)	difference in scores (a)-(b)
1	no	data	-	-	-	-	-
2	5	65.0	5	64.0	10	64.0	1.00
3	6	74.2	4	85.0	10	78.5	-10.80
4	5	70.0	5	49.0	10	67.5	21.00
5	5	51.0	5	37.0	10	44.0	14.00
6	5	89.5	5	83.0	10	85.8	6.50
7	4	71.3	5	75.0	9	73.3	- 3.75
8	5	51.0	5	57.0	10	54.0	- 6.00
9	6	70.8	4	66.3	10	69.0	4.50
10	7	71.4	3	76.7	10	73.0	- 5.27
11	4	76.3	5	75.0	9	75.5	1.25
12	5	68.0	4	63.8	9	66.1	5.75
13	4	77.5	5	65.0	9	71.1	12.50
14	5	69.0	5	71.0	10	70.0	- 2.00
15	4	67.5	5	70.0	9	68.9	- 2.50
16	5	61.0	5	53.0	10	57.0	8.00
18	5	81.0	5	51.0	10	66.0	30.00
19	5	51.0	5	53.0	10	52.0	- 2.00
20	5	79.0	5	80.0	10	79.5	- 1.00
21	5	77.0	5	80.0	10	78.5	- 3.00
23	5	85.0	5	73.0	10	79.0	12.00
24	5	70.0	5	60.0	10	65.0	10.00
25	5	62.0	5	68.0	10	65.0	- 6.0
26	6	71.7	4	83.8	10	77.0	-12.10
27	6	89.5	5	86.0	10	87.8	3.50
28	5	89.5	5	86.0	10	87.0	3.50

calculations on columns (a) and (b)

$\bar{x}_a = 70.15$ $\quad$ $\bar{x}_b = 67.62$

$\Sigma x_a = 1753.63$ $\quad$ $\Sigma x_b = 1690.55$

$\Sigma x_a^2 = 125885.03$ $\quad$ $\Sigma x_b^2 = 118203.08$

$s_a = 10.95 \quad n_a = 25$ $\quad$ $s_b = 12.72 \quad n_b = 25$

calculation of t: difference between means of two samples

general equation: $t = \dfrac{x_a - x_b}{s\ (\ (1/n_a + 1/n_b))}$

$$s^2 = \frac{1}{50-2}\left(125885.03 - \frac{1753.63^2}{25} + 118203.08 - \frac{1690.55^2}{25}\right) = 140.85$$

$s = s^2 = 11.87$

therefore: $t = \dfrac{70.15-67.62}{11.87(\ 1/25 + 1/25))} = 0.75$ with 48 d.f.

Probability of this value of t is greater than $p = 0.1$. The difference between means is therefore not significant.

Fig. D2 Lichen Board Survey 2: sample score sheet for recording photographic data

LICHEN BOARD SURVEY 2

BOARD NO.

KEY

	a	b	c	d	e		a	b	c	d	e

Table D6 Lichen Board Survey 2: summarised data for boards and weeks (all replicates)

```
MTB > TABLE C9 C10;
MTB > MEAN C12;
MTB > STDEV C12;
MTB > NONMISSING C12.
```

ROWS: C9 COLUMNS: C10

	0	4	6	8	12	18	20	26
1	96.88	93.13	96.88	96.88	96.88	77.50	75.00	67.50
	0.00	5.13	0.00	0.00	0.00	5.59	8.84	6.85
	5	5	5	5	5	5	5	5
2	96.88	91.25	91.25	91.25	91.25	15.62	13.75	11.25
	0.00	5.13	5.13	5.13	5.13	9.38	10.96	9.00
	5	5	5	5	5	5	5	5
3	96.88	95.00	95.00	95.00	95.00	82.50	82.50	86.87
	0.00	4.19	4.19	4.19	4.19	6.85	6.85	7.78
	5	5	5	5	5	5	5	5
4	96.88	96.88	96.88	96.88	96.88	95.00	89.37	91.25
	0.00	0.00	0.00	0.00	0.00	4.19	4.19	5.13
	5	5	5	5	5	5	5	5
5	96.88	93.13	93.13	93.13	93.13	85.63	85.63	85.63
	0.00	5.13	5.13	5.13	5.13	16.03	16.03	16.03
	5	5	5	5	5	5	5	5
6	96.88	96.88	96.88	96.88	96.88	95.00	95.00	95.00
	0.00	0.00	0.00	0.00	0.00	4.19	4.19	4.19
	5	5	5	5	5	5	5	5
7	96.88	95.00	95.00	95.00	95.00	--	--	--
	0.00	4.19	4.19	4.19	4.19	--	--	--
	5	5	5	5	5	0	0	0
8	96.88	96.88	96.88	96.88	96.88	77.50	60.00	57.50
	0.00	0.00	0.00	0.00	0.00	5.59	10.46	6.85
	5	5	5	5	5	5	5	5
9	96.88	95.00	95.00	95.00	95.00	47.50	42.50	40.00
	0.00	4.19	4.19	4.19	4.19	10.46	16.77	16.30
	5	5	5	5	5	5	5	5
10	96.88	96.88	96.88	96.88	96.88	89.37	84.38	--
	0.00	0.00	0.00	0.00	0.00	4.19	12.88	--
	5	5	5	5	5	5	5	0
11	96.88	95.00	95.00	93.13	93.13	84.38	84.38	84.38
	0.00	4.19	4.19	5.13	5.13	9.38	9.38	9.38
	5	5	5	5	5	5	5	5
12	96.88	96.88	96.88	96.88	78.13	18.75	14.38	19.38
	0.00	0.00	0.00	0.00	41.93	24.90	20.32	31.36
	5	5	5	5	5	5	5	5

Table D6 cont.

	0	4	6	8	12	18	20	26
13	96.88	93.13	93.13	90.63	90.63	72.50	58.12	51.25
	0.00	5.13	5.13	9.63	9.63	16.30	34.77	44.23
	5	5	5	5	5	5	5	5
14	96.88	96.88	96.88	96.88	96.88	85.00	85.00	85.00
	0.00	0.00	0.00	0.00	0.00	5.59	5.59	5.59
	5	5	5	5	5	5	5	5
15	96.88	96.88	96.88	96.88	96.88	87.50	89.37	89.37
	0.00	0.00	0.00	0.00	0.00	0.00	4.19	4.19
	5	5	5	5	5	5	5	5
16	96.88	96.88	96.88	96.88	96.88	82.50	84.38	80.00
	0.00	0.00	0.00	0.00	0.00	6.85	9.38	6.85
	5	5	5	5	5	5	5	5
18	96.88	93.13	76.25	76.25	76.25	62.50	53.13	58.12
	0.00	5.13	35.94	35.94	35.94	27.95	36.84	33.63
	5	5	5	5	5	5	5	5
20	96.88	93.13	93.13	88.13	90.63	42.50	38.13	37.50
	0.00	5.13	5.13	11.98	9.63	25.92	26.92	26.52
	5	5	5	5	5	5	5	5
21	96.88	96.88	96.88	96.88	96.88	86.87	89.37	86.87
	0.00	0.00	0.00	0.00	0.00	7.78	4.19	7.78
	5	5	5	5	5	5	5	5
22	96.88	95.00	95.00	95.00	95.00	75.00	81.88	70.00
	0.00	4.19	4.19	4.19	4.19	12.50	13.33	14.25
	5	5	5	5	5	5	5	5
23	96.88	95.00	96.88	96.88	95.00	47.50	52.50	45.00
	0.00	4.19	0.00	0.00	4.19	18.54	10.46	14.25
	5	5	5	5	5	5	5	5
24	96.88	95.00	93.13	95.00	95.00	91.25	93.13	93.13
	0.00	4.19	5.13	4.19	4.19	5.13	5.13	5.13
	5	5	5	5	5	5	5	5
25	96.88	84.38	84.38	84.38	84.38	77.50	60.00	52.50
	0.00	9.38	9.38	9.38	9.38	10.46	22.36	25.62
	5	5	5	5	5	5	5	5
26	96.88	89.37	91.25	89.37	91.25	--	85.00	85.00
	0.00	4.19	5.13	4.19	5.13	--	5.59	5.59
	5	5	5	5	5	0	5	5
27	96.88	96.88	96.88	95.00	96.88	--	--	--
	0.00	0.00	0.00	4.19	0.00	--	--	--
	5	5	5	5	5	0	0	0
28	96.88	95.00	95.00	95.00	95.00	77.50	80.00	70.00
	0.00	4.19	4.19	4.19	4.19	10.46	11.18	14.25
	5	5	5	5	5	5	5	5

Table D6 cont.

	0	4	6	8	12	18	20	26
29	96.88	93.13	93.13	91.25	93.13	82.50	80.00	86.87
	0.00	5.13	5.13	5.13	5.13	6.85	6.85	7.78
	5	5	5	5	5	5	5	5
30	96.88	96.88	96.88	96.88	96.88	85.00	82.50	65.63
	0.00	0.00	0.00	0.00	0.00	5.59	6.85	35.49
	5	5	5	5	5	5	5	5
31	96.88	95.00	95.00	95.00	95.00	82.50	81.88	77.50
	0.00	4.19	4.19	4.19	4.19	6.85	13.33	10.46
	5	5	5	5	5	5	5	5
32	96.88	85.00	87.50	85.00	82.50	50.00	45.00	42.50
	0.00	5.59	0.00	5.59	6.85	23.39	20.92	18.96
	5	5	5	5	5	5	5	5
33	96.88	96.88	96.88	95.00	95.00	6.88	6.88	6.88
	0.00	0.00	0.00	4.19	4.19	5.13	5.13	5.13
	5	5	5	5	5	5	5	5
34	96.88	96.88	96.88	96.88	96.88	86.87	86.87	86.87
	0.00	0.00	0.00	0.00	0.00	7.78	7.78	7.78
	5	5	5	5	5	5	5	5
35	96.88	95.00	95.00	92.50	92.50	45.00	59.38	--
	0.00	4.19	4.19	9.78	9.78	18.96	11.97	--
	5	5	5	5	5	5	4	0
36	96.88	95.00	95.00	95.00	96.88	65.63	68.13	65.63
	0.00	4.19	4.19	4.19	0.00	35.49	36.74	36.58
	5	5	5	5	5	5	5	5
37	96.88	95.00	95.00	92.50	95.00	82.50	85.00	85.00
	0.00	4.19	4.19	9.78	4.19	6.85	5.59	5.59
	5	5	5	5	5	5	5	5
38	96.88	95.00	96.88	96.88	95.00	27.50	25.63	23.13
	0.00	4.19	0.00	0.00	4.19	10.46	14.05	12.42
	5	5	5	5	5	5	5	5
ALL	96.88	94.53	94.34	93.72	93.37	68.83	67.64	65.08
	0.06	4.60	7.47	8.21	10.53	27.19	28.44	29.99
	180	180	180	180	180	165	169	160

Table D7 Lichen Board Survey 2: summarised data for boards and weeks, excluding replicates with greater than 50% material lost.

```
MTB > TABLE C9 C10;
MTB > MEAN C12;
MTB > STDEV C12;
MTB > NONMISSING C12.
```

ROWS: C9 COLUMNS: C10

	0	4	6	8	12	18	20	26
1	96.88	92.19	96.88	96.88	96.88	75.00	71.88	65.63
	0.00	5.41	0.00	0.00	0.00	0.00	6.25	6.25
	5	4	4	4	4	3	4	4
2	96.88	91.25	91.25	91.25	89.84	18.75	17.71	13.54
	0.00	5.13	5.13	5.13	4.69	7.22	12.63	10.97
	5	5	5	5	4	4	3	3
3	96.88	95.00	95.00	95.00	95.00	82.50	82.50	86.87
	0.00	4.19	4.19	4.19	4.19	6.85	6.85	7.78
	5	5	5	5	5	5	5	5
4	96.88	96.88	96.88	96.88	96.88	95.00	89.37	91.25
	0.00	0.00	0.00	0.00	0.00	4.19	4.19	5.13
	5	5	5	5	5	5	5	5
5	96.88	93.13	93.13	93.13	93.13	85.63	85.63	88.28
	0.00	5.13	5.13	5.13	5.13	16.03	16.03	17.19
	5	5	5	5	5	5	5	4
6	96.88	96.88	96.88	96.88	96.88	95.00	95.00	95.00
	0.00	0.00	0.00	0.00	0.00	4.19	4.19	4.19
	5	5	5	5	5	5	5	5
7	96.88	95.00	95.00	95.00	95.00	--	--	--
	0.00	4.19	4.19	4.19	4.19	--	--	--
	5	5	5	5	5	0	0	0
8	96.88	96.88	96.88	96.88	96.88	77.50	60.00	57.50
	0.00	0.00	0.00	0.00	0.00	5.59	10.46	6.85
	5	5	5	5	5	5	5	5
9	96.88	95.00	95.00	95.00	95.00	47.50	42.50	40.00
	0.00	4.19	4.19	4.19	4.19	10.46	16.77	16.30
	5	5	5	5	5	5	5	5
10	96.88	96.88	96.88	96.88	96.88	89.37	84.38	--
	0.00	0.00	0.00	0.00	0.00	4.19	12.88	--
	5	5	5	5	5	5	5	0
11	96.88	95.00	95.00	93.13	93.13	84.38	84.38	84.38
	0.00	4.19	4.19	5.13	5.13	9.38	9.38	9.38
	5	5	5	5	5	5	5	5
12	96.88	96.88	96.88	96.88	96.88	22.66	31.25	43.75
	0.00	0.00	0.00	0.00	0.00	26.93	26.52	44.19
	5	5	5	5	4	4	2	2

Table D7 cont.

	0	4	6	8	12	18	20	26
13	96.88 0.00 5	93.13 5.13 5	93.13 5.13 5	90.63 9.63 5	89.06 10.36 4	78.13 11.97 4	71.88 18.75 4	83.33 7.22 3
14	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	85.00 5.59 5	85.00 5.59 5	85.00 5.59 5
15	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	87.50 0.00 5	89.37 4.19 5	89.37 4.19 5
16	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	82.50 6.85 5	84.38 9.38 5	80.00 6.85 5
18	96.88 0.00 5	93.13 5.13 5	76.25 35.94 5	76.25 35.94 5	76.25 35.94 5	75.00 0.00 3	79.17 7.22 3	79.17 7.22 3
20	96.88 0.00 5	93.13 5.13 5	93.13 5.13 5	88.13 11.98 5	90.63 9.63 5	42.50 25.92 5	38.13 26.92 5	37.50 26.52 5
21	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	86.87 7.78 5	89.37 4.19 5	86.87 7.78 5
22	96.88 0.00 5	95.00 4.19 5	95.00 4.19 5	95.00 4.19 5	95.00 4.19 5	75.00 12.50 5	81.88 13.33 5	70.00 14.25 5
23	96.88 0.00 5	95.00 4.19 5	96.88 0.00 5	96.88 0.00 5	95.00 4.19 5	47.50 18.54 5	52.50 10.46 5	45.00 14.25 5
24	96.88 0.00 5	95.00 4.19 5	93.13 5.13 5	95.00 4.19 5	95.00 4.19 5	91.25 5.13 5	93.13 5.13 5	93.13 5.13 5
25	96.88 0.00 5	84.38 9.38 5	84.38 9.38 5	84.38 9.38 5	84.38 9.38 5	77.50 10.46 5	60.00 22.36 5	52.50 25.62 5
26	96.88 0.00 5	89.37 4.19 5	91.25 5.13 5	89.37 4.19 5	91.25 5.13 5	-- -- 0	85.00 5.59 5	85.00 5.59 5
27	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	95.00 4.19 5	96.88 0.00 5	-- -- 0	-- -- 0	-- -- 0
28	96.88 0.00 5	95.00 4.19 5	95.00 4.19 5	95.00 4.19 5	95.00 4.19 5	77.50 10.46 5	80.00 11.18 5	70.00 14.25 5

Table D7 cont.

	0	4	6	8	12	18	20	26
29	96.88 0.00 5	93.13 5.13 5	93.13 5.13 5	91.25 5.13 5	93.13 5.13 5	82.50 6.85 5	80.00 6.85 5	75.00 -- 1
30	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	85.00 5.59 5	82.50 6.85 5	81.25 7.22 4
31	96.88 0.00 5	95.00 4.19 5	95.00 4.19 5	95.00 4.19 5	95.00 4.19 5	82.50 6.85 5	81.88 13.33 5	77.50 10.46 5
32	96.88 0.00 5	85.00 5.59 5	87.50 0.00 5	85.00 5.59 5	82.50 6.85 5	50.00 23.39 5	45.00 20.92 5	42.50 18.96 5
33	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	95.00 4.19 5	95.00 4.19 5	6.88 5.13 5	6.88 5.13 5	6.88 5.13 5
34	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	96.88 0.00 5	86.87 7.78 5	86.87 7.78 5	86.87 7.78 5
35	96.88 0.00 5	95.00 4.19 5	95.00 4.19 5	91.41 10.94 4	91.41 10.94 4	50.00 17.68 4	59.38 11.97 4	-- -- 0
36	96.88 0.00 5	95.00 4.19 5	95.00 4.19 5	95.00 4.19 5	96.88 0.00 4	81.25 7.22 4	84.38 6.25 4	81.25 12.50 4
37	96.88 0.00 5	95.00 4.19 5	95.00 4.19 5	92.50 9.78 5	95.00 4.19 5	82.50 6.85 5	85.00 5.59 5	85.00 5.59 5
38	96.88 0.00 5	95.00 4.19 5	96.88 0.00 5	96.88 0.00 5	95.00 4.19 5	27.50 10.46 5	25.63 14.05 5	23.13 12.42 5
ALL	96.88 0.06 180	94.52 4.61 179	94.33 7.49 179	93.68 8.24 178	93.79 8.20 174	70.65 25.65 156	70.97 25.12 159	68.62 26.66 143

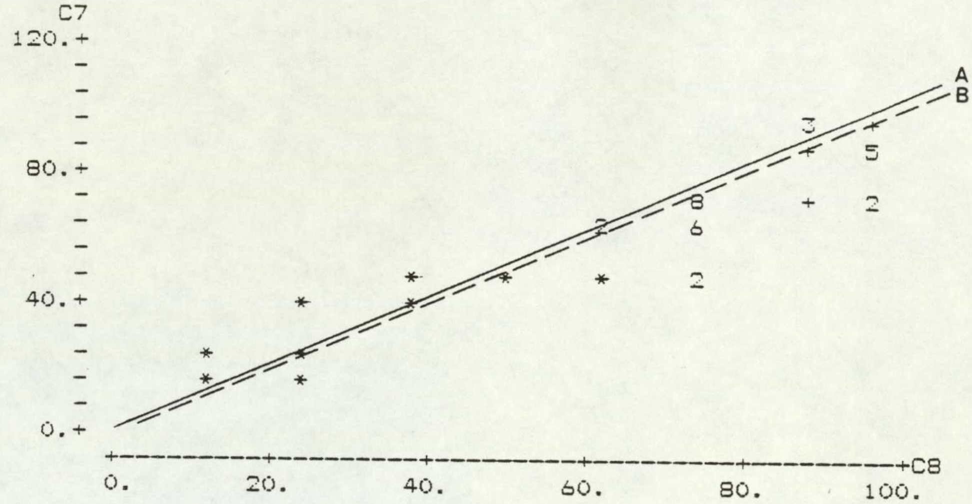
Table D8 Lichen Board Survey 2: Test of reproducibility of scores

In the test below 30 photographs were rescored. Score 1 is the original survey data; score 2 is the "reproduced" score.

<u>COMPUTER PRINTOUT (MINITAB STATISTICAL PACKAGE)</u>

A = expected regression line (r=1)
B = regression line of equation below

```
MTB > £
MTB > £
MTB > £SCATTERPLOT OF SCORE 1 (C7) VS SCORE 2 (C8)
MTB > £
MTB > £
MTB > PLOT C7 VS C8
```




```
MTB > £
MTB > £
MTB > £REGRESSION ANALYSIS
MTB > £
MTB > £
MTB > REGRESS C7 1 C8,C9

THE REGRESSION EQUATION IS
C7 = - 0.99 + 0.978 C8

                                    ST. DEV.    T-RATIO =
COLUMN       COEFFICIENT            OF COEF.    COEF/S.D.
                 -0.989              2.962        -0.33
C8              0.97830             0.03355       29.16

S = 6.680

R-SQUARED = 85.3 PERCENT
R-SQUARED = 85.2 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

 DUE TO       DF           SS       MS=SS/DF
REGRESSION     1        37939          37939
RESIDUAL     146         6515             45
TOTAL        147        44454
```

Table D8 cont

ROW	C8	Y C7	PRED. Y VALUE	ST.DEV. PRED. Y	RESIDUAL	ST.RES.
1	12.5	25.000	11.239	2.551	13.761	2.23RX
3	50.0	50.000	47.926	1.349	2.074	0.32 X
5	75.0	50.000	72.383	0.676	-22.383	-3.37R
38	96.9	75.000	93.783	0.646	-18.783	-2.83R
86	96.9	75.000	93.783	0.646	-18.783	-2.83R
130	75.0	50.000	72.383	0.676	-22.383	-3.37R
140	25.0	12.500	23.468	2.143	-10.968	-1.73 X
144	25.0	25.000	23.468	2.143	1.532	0.24 X
145	25.0	37.500	23.468	2.143	14.032	2.22RX
146	37.5	37.500	35.697	1.741	1.803	0.28 X
147	12.5	12.500	11.239	2.551	1.261	0.20 X
148	37.5	50.000	35.697	1.741	14.303	2.22RX

R DENOTES AN OBS. WITH A LARGE ST. RES.
X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.

```
MTB > £
MTB > £
MTB > £CORRELATION OF SCORES
MTB > £
MTB >
MTB >CORR C7 C8

    CORRELATION OF   SCORE1 AND SCORE2  = 0.924
```

Trial	A Score 1	B Score 2	B-A Difference
1	47.50	52.50	5.00
2	96.88	95.00	- 1.88
3	83.33	85.00	- 1.67
4	77.50	81.88	4.38
5	93.75	93.75	0.00
6	93.75	95.00	- 1.88
7	95.00	95.00	0.00
8	91.41	95.00	3.59
9	81.88	85.00	3.13
10	90.63	94.53	3.91
11	83.75	88.13	4.38
12	95.00	95.00	0.00
13	93.13	93.13	0.00
14	96.88	96.88	0.00
15	82.50	89.38	6.88
16	95.00	95.00	0.00
17	77.50	84.38	6.88
18	88.13	95.00	6.88
19	95.00	95.00	0.00
20	77.50	82.50	5.00
21	93.13	93.13	0.00
22	95.00	96.88	1.88
23	80.00	85,00	5.00
24	79.38	84.38	5.00
25	84.38	84.38	0.00
26	92.50	95.00	2.50
27	70,00	82.50	12.50
28	90.62	93.13	2.50
29	56.63	65.63	9.00
30	32.50	27.50	- 5.00

Table D9 Survey 1 and Survey 2: correlation of %green scores with site factors.

The table below lists the various factors which were compared (using linear regression analysis) with % green scores. No significant regression was found for these factors, either singly or in combination.

KEY: L1MEAN and L2MEAN = % green score
MAPN and MAPE = map reference
HEIGHT = ht above sea level (m)

MTB > print c1 c2-c7 c9-c12

ROW	BOARD	SURVEY	L1MEAN	L2MEAN	MAPN	MAPE	HEIGHT
1	1	3	0.00	65.63	37	20	137
2	2	3	64.00	13.54	32	25	135
3	3	3	78.50	86.88	29	17	*
4	4	3	67.50	91.25	37	34	105
5	5	3	44.00	88.28	34	43	96
6	6	3	86.25	95.00	39	28	112
7	7	1	73.33	*	43	31	135
8	8	3	54.00	57.50	42	22	150
9	9	3	69.00	40.00	54	29	148
10	10	3	73.00	84.40	53	35	141
11	11	3	75.56	84.38	51	31	135
12	12	3	66.11	43.75	51	37	182
13	13	3	70.63	83.33	50	37	176
14	14	3	70.00	85.00	59	35	142
15	15	3	69.44	89.38	60	40	*
16	16	3	57.00	80.00	63	32	165
17	18	3	67.00	79.18	66	34	177
18	19	1	52.00	*	61	38	*
19	20	3	79.50	37.50	64	39	165
20	21	3	78.50	86.88	70	42	*
21	22	2	*	70.00	46	10	*
22	23	1	79.00	*	40	30	*
23	23	2	*	45.00	43	50	*
24	24	3	65.00	93.13	43	32	115
25	25	1	65.00	*	44	32	110
26	25	2	*	52.50	43	31	110
27	26	3	76.50	85.00	44	28	*
28	27	3	87.75	*	45	23	135
29	28	3	59.50	70.00	18	14	*
30	29	2	*	75.00	54	32	*
31	30	2	*	81.25	75	43	*
32	31	2	*	77.50	72	33	*
33	32	2	*	42.50	71	22	*
34	33	2	*	6.88	63	23	160
35	34	2	*	86.88	64	15	*
36	35	2	*	44.50	18	42	*
37	36	2	*	81.25	21	30	*
38	37	2	*	85.00	32	48	*
39	38	2	*	23.13	35	15	*

Table D10 Lichen Board Survey 2: F-distribution test on results of linear regression analysis.

Board	Coef.[1]	F	d.f.[2]	Sig.[3]
1	-1.35	26.93	1,6	***
2	-4.02	31.12	1,6	***
3	-0.57	14.34	1,6	**
4	-0.28	12.32	1,6	*
5	-0.40	18.29	1,6	**
6	-0.11	23.55	1,5	***
7	-0.14	3.86	1,3	NSD
8	-1.78	26.87	1,6	***
9	-2.76	29.49	1,6	***
10	-0.59	13.11	1,5	*
11	-0.58	51.94	1,6	***
12	-3.17	14.03	1,6	**
13	-0.80	13.70	1,6	*
14	-0.61	23.06	1,6	***
15	-0.41	16.88	1,6	**
16	-0.78	28.91	1,6	***
18	-0.58	3.27	1,6	NSD
20	-2.86	34.93	1,6	***
21	-0.48	22.98	1,6	***
22	-1.10	30.60	1,6	***
23	-2.52	26.85	1,6	***
24	-0.14	6.10	1,6	*
25	-1.52	37.16	1,6	***
26	-0.38	13.99	1,5	*
27	-0.05	0.20	1,3	NSD
28	-1.10	40.34	1,6	***
29	-0.85	71.01	1,6	***
30	-0.75	30.14	1,6	***
31	-0.82	46.87	1,6	***
32	-2.36	60.47	1,6	***
33	-4.65	24.42	1,6	***
34	-0.52	23.07	1,6	***
35	-2.35	18.41	1,5	**
36	-0.70	22.03	1,6	***
37	-0.57	21.84	1,6	***
38	-3.71	25.98	1,6	***
40	-0.27	7.43	1,6	*
41	-0.15	9.29	1,6	*
42	-0.61	54.99	1,6	***
43	-0.28	36.00	1,6	***
44[4]	0.00	-	1,2	-
45[4]	-0.32	17.67	1,2	NSD

Note [1] gradient of regression line
[2] degrees of freedom
[3] significance of F value; probability levels *=5% **=1% ***=0.5% NSD= no significant difference
[4] control boards C1 and C2

Table D11 Lichen Board Survey 2: Comparison of scores obtained "objectively" (using matrix overlay) against scores obtained "by eye".

Trial	A "objective" score	B "by eye" score	C Difference in scores	D no. reps
1	95.00	93.13	1.88	5
2	72.50	77.50	-5.00	5
3	95.00	96.88	-1.88	5
4	96.88	96.88	0.00	5
5	96.88	96.88	0.00	4
6	95.00	93.13	1.88	5
7	93.13	86.88	6.25	5
8	93.13	93.13	0.00	5
9	95.00	95.00	0.00	5
10	96.88	96.88	0.00	4
11	85.94	81.25	4.69	4
12	88.13	85.68	3.50	5
13	91.25	85.00	6.25	5
14	81.25	71.88	9.63	4
15	84.38	81.88	2.50	5
16	81.25	75.00	6.25	4
17	86.88	84.38	2.50	5
18	25.63	23.13	2.50	5

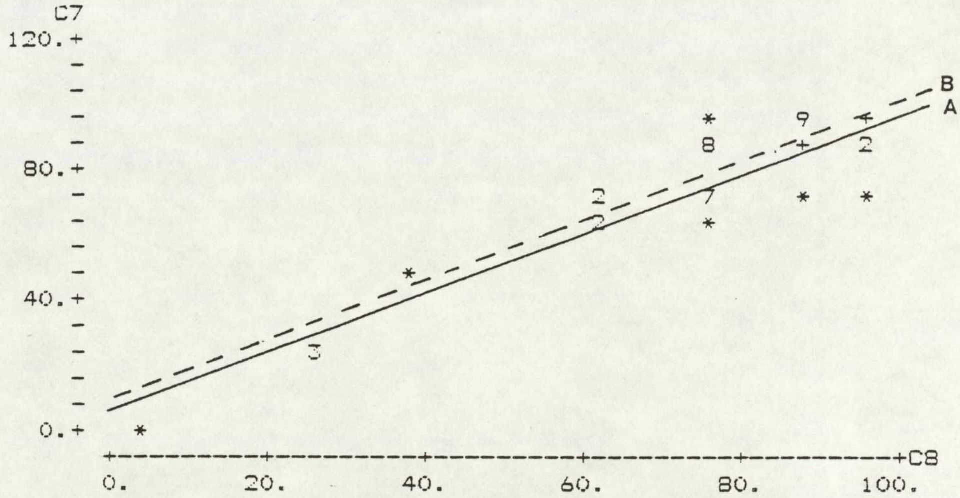
Note: A and B are mean scores per board, with number of valid replicates per board as in D. C is the difference between mean scores A and B.

Further analysis: overleaf

A = expected regression line (r=1)
B = regression line of equation overleaf

PRINTOUT (MINITAB)

```
MTB >
MTB >£SCATTERPLOT OF 'OBJECTIVE' SCORE (C7) VS 'BY EYE' SCORE (C8)
MTB >
MTB >
```




```
MTB >REGRESS C7 1 C8,C9

THE REGRESSION EQUATION IS
C7 = 9.15 + 0.916 C8
```

COLUMN	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO = COEF/S.D.
	9.150	3.195	2.86
C8	0.91586	0.03700	24.76

S = 6.310

R-SQUARED = 87.8 PERCENT
R-SQUARED = 87.7 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

DUE TO	DF	SS	MS=SS/DF
REGRESSION	1	24402	24402
RESIDUAL	85	3384	40
TOTAL	86	27786	

ROW	C8	Y C7	PRED. Y VALUE	ST.DEV. PRED. Y	RESIDUAL	ST.RES.
8	87.5	75.000	89.287	0.686	-14.287	-2.28R
10	75.0	62.500	77.839	0.761	-15.339	-2.45R
58	96.9	75.000	97.874	0.819	-22.874	-3.66R
59	75.0	96.875	77.839	0.761	19.036	3.04R
83	25.0	25.000	32.046	2.300	-7.046	-1.20 X
84	25.0	25.000	32.046	2.300	-7.046	-1.20 X
85	25.0	25.000	32.046	2.300	-7.046	-1.20 X
86	3.1	3.125	12.012	3.082	-8.887	-1.61 X
87	37.5	50.000	43.495	1.863	6.505	1.08 X

```
R DENOTES AN OBS. WITH A LARGE ST. RES.
X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.

DURBIN-WATSON STATISTIC = 1.94

MTB >CORR C7 C8

   CORRELATION OF        C7 AND C8       = 0.937
```

APPENDIX E

University of Birmingham climatological data for the distribution of wind direction during lichen board surveys 1 and 2

Table E1 The distribution of wind direction for the period December 1983 to June 1984, compiled from monthly climatological summary data: Meteorological Services Unit, University of Birmingham (Edgbaston).

Dir	Dec	Jan	Feb	Mar	Apr	May	Jun	total	%
N	11	8	46	21	23	48	31	188	3.7
NNE	6	7	97	169	76	107	21	483	9.4
NE	3	4	7	62	67	138	7	288	5.6
ENE	8	14	29	53	79	133	4	320	6.3
E	45	29	79	28	65	31	10	287	5.6
ESE	43	27	22	18	12	35	18	175	3.4
SE	23	20	11	19	1	28	7	109	2.1
SSE	52	24	46	17	3	17	13	172	3.4
S	53	17	29	14	20	5	6	144	2.8
SSW	111	86	27	14	102	17	27	384	7.5
SW	188	131	43	36	61	8	63	530	10.4
WSW	62	90	42	23	15	4	42	278	5.4
W	34	122	61	54	17	8	41	337	6.6
WNW	32	84	82	76	49	12	128	463	9.1
NW	36	48	20	80	71	55	123	433	8.4
NNW	24	33	13	45	34	83	126	358	7.0
Calm	13	0	42	15	25	15	53	163	3.2
Total	744	744	696	744	720	744	720	5122	-

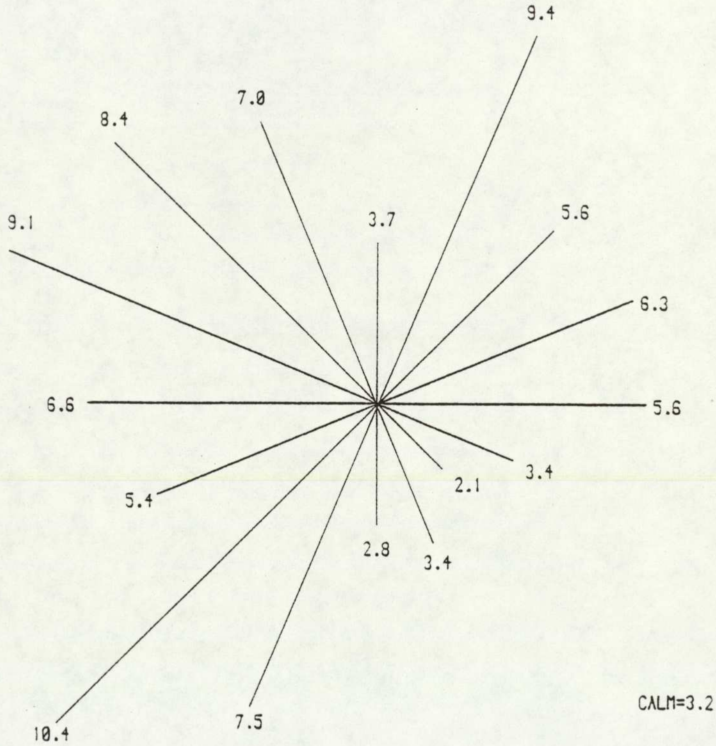
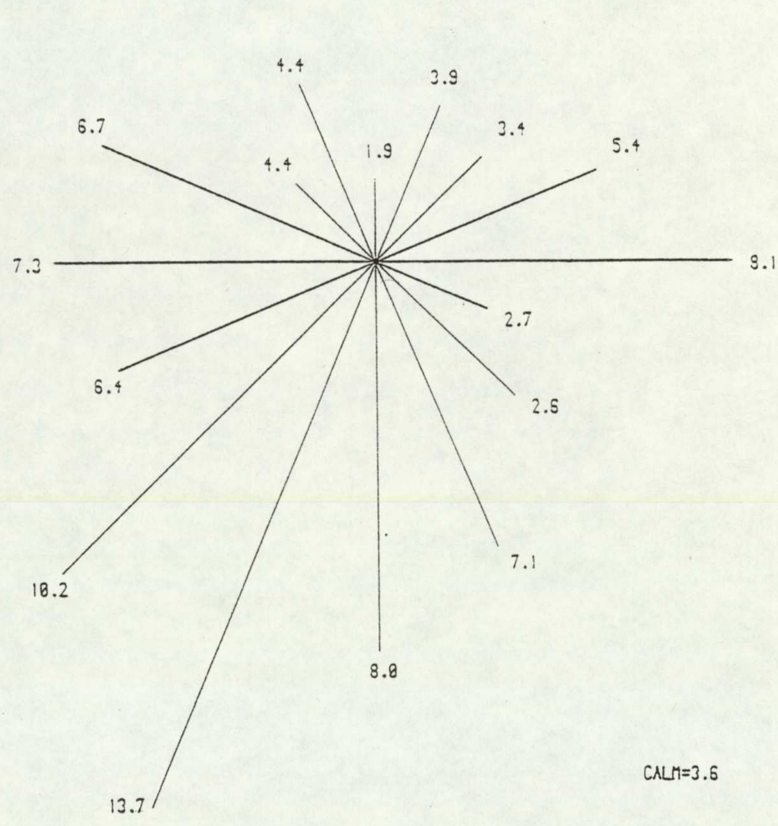


Table E2 The distribution of wind direction for the period October 1984 to April 1985, compiled from monthly climatological summary data: Meteorological Services Unit, University of Birmingham (Edgbaston).

Dir	Oct	Nov	Dec	Jan	Feb	Mar	Apr	total	%
N	8	11	2	43	0	20	14	98	1.9
NNE	7	38	9	105	1	29	10	199	3.9
NE	3	41	5	43	13	20	47	172	3.4
ENE	1	18	11	60	143	19	25	277	5.4
E	7	34	69	52	170	64	18	414	8.1
ESE	6	27	24	16	36	19	11	139	2.7
SE	20	37	25	17	13	6	13	131	2.6
SSE	81	96	91	13	37	21	23	362	7.1
S	99	68	113	12	48	32	35	407	8.0
SSW	177	84	137	48	70	90	92	698	13.7
SW	113	94	80	43	54	73	61	518	10.2
WSW	75	48	39	38	17	53	56	326	6.4
W	65	30	59	39	33	76	69	371	7.3
WNW	32	26	40	38	11	85	111	343	6.7
NW	14	14	11	50	1	45	91	226	4.4
NNW	11	15	12	112	0	51	23	224	4.4
Calm	25	39	17	15	25	41	21	183	3.6
Total	744	720	744	744	672	744	720	5088	-



APPENDIX F

Lichen Board Survey 1: metal analysis

Lichen Board Survey 1: metal analysis

Background information

The first lichen board survey was carried out in the winter of 1983/4, as described in Chapter 4. In order to obtain some extra data from this survey and to provide a comparison with metal levels, measured by mossbags for the same area, some of the lichen discs were analysed for trace metals. Following completion of the lichen survey, discs taken from ten of the exposed boards together with some of the unexposed lichen material, were sent to New Era Laboratory in London for analysis of trace metals . The analysis procedure, which is principally designed for hair analysis, is described in Appendix C. The results obtained are presented in Table F1.

Table F1 Lichen Board Survey 1: results of trace metal analysis (mg/kg dry wt) by New Era Laboratory.

Metal	Lichen sample		(board and disc number)								
	Blank[1] 1	Blank 2	2j	5e	6f	9d	10j	12b	14i	20i	28h
Al	577.59	289.82	819.32	970.64	1277.75	2847.69	1014.00	1052.39	614.71	2772.59	1015.32
Cd	1.54	0.79	2.21	3.21	4.25	10.62	3.40	4.01	4.08	7.11	3.35
Cr	3.05	* 1.31	7.67	8.21	28.19	52.62	9.40	20.82	32.81	60.67	7.32
Cu	10.90	9.29	62.79	75.20	100.72	185.24	83.62	91.61	102.16	241.01	42.62
Fe	863.69	535.17	2375.99	2513.19	6023.07	19473.12	2959.85	3397.94	4877.77	10141.31	2091.27
K	3735.13	4829.88	1669.57	3798.91	9997.21	3217.96	3910.96	4931.92	2213.20	8181.81	6189.53
Mn	420.63	242.70	200.39	292.31	301.46	496.60	232.38	164.44	251.81	373.28	268.51
Ni	5.87	1.77	6.58	16.93	35.52	48.24	10.40	34.27	18.70	30.56	9.02
P	984.10	1247.08	1051.68	2194.37	3769.04	1865.58	1421.94	2056.66	684.26	2581.27	1762.92
Pb	81.21	* 9.56	75.52	75.24	77.00	152.69	48.55	59.42	74.70	234.52	60.04
Zn	107.45	106.38	239.09	514.80	617.08	949.82	411.92	610.45	2404.29	1041.76	198.85

Note [1] unexposed moss
* below level of detection

APPENDIX G

Lichen Board Surveys: costs

Table Gl Lichen board survey 1983/4: analysis of costs (adjusted to 1985 prices).

Item	amount		cost (£)
MATERIALS			
Boards (timber)	30 @ £1.00		30.00
Araldite (tubes)	6 @ £9.00		54.00
Wire (roll)	1 @ £2.00		2.00
Film (Kodacolor II 36 exp. print)	8 @ £3.25		26.00
Kodak Gray Scale	1 @ £5.00		5.00
Flash unit batteries	16 @ £0.50		8.00
		sub total	125.00
LABOUR[1]			
Identification of sites	8hr* @ £8.00		64.00
Collection of lichen	8hr* @£ 8.00		64.00
Board construction	6hr @ £8.00		48.00
Board assembly	15hr @ £8.00		120.00
Positioning boards on site	24hr* @ £8.00		192.00
Photographing boards[2]	7 x 8hr* @ £8.00		448.00
Collection of boards/other	4hr @ £8.00		32.00
Film processing costs	8 @ £4.50		36.00
Scoring photographs	4hr @ £8.00		32.00
		sub total	1046.00
TRANSPORT[3]			
Journey to Shropshire control site (120 miles)	3 @ £24		72.00
Journey to Blackbrook Valley (35 miles)	10 @ £7		70.00
		sub total	140.00
		TOTAL	1311.00

Notes
* Task shared by two people.
[1] labour costs estimated at £8 per hour.
[2] control boards photographed in laboratory
[3] travel costs estimated at 20 pence per mile

Table G2 Lichen Board Survey 2: analysis of costs.

Item	amount		cost (£)
MATERIALS			
Boards (timber)	45 @ £0.50		22.50
Araldite (tubes)	3 @ £9.00		27.00
Wire (roll)	1 @ £2.00		2.00
Film (Kodacolor II 24 exp. print)	16 @ £2.90		46.40
Kodak Gray Scale	1 @ £5.00		5.00
Flash unit batteries	16 @ £0.50		8.00
		sub total	110.90
LABOUR[1]			
Identification of sites	4hr* @ £8.00		64.00
Collection of lichen	8hr* @£ 8.00		64.00
Board construction	4hr @ £8.00		32.00
Board assembly	10hr @ £8.00		80.00
Positioning boards on site	24hr* @ £8.00		192.00
Photographing boards[2]	7 x 12hr* @ £8.00		672.00
Collection of boards/other	4hr @ £8.00		32.00
Film processing costs	16 @ £4.00		48.00
Scoring photographs	3hr @ £8.00		24.00
		sub total	1208.00
TRANSPORT[3]			
Journey to Shropshire control site (120 miles)	4 @ £24.00		96.00
Journey to Blackbrook Valley (45 miles)	11 @ £9.00		99.00
		sub total	195.00
		TOTAL	1513.90

Notes
* Task shared by two people.
[1] labour costs estimated at £8 per hour.
[2] control boards photographed in laboratory
[3] travel costs estimated at 20 pence per mile

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