8th Annual ITEX Workshop

Royal Holloway Institute for Environmental Research
19-22 April 1997

SUMMARY DOCUMENT

1. Introduction & Objectives

The 8th Annual ITEX Workshop attracted 44 delegates from a total of 14 countries and convened at the Royal Holloway Institute for Environmental Research, Surrey, England. The format for the meeting was based upon a combination of:

1. key-note **Plenary Presentations**, designed to prompt critical discussion,
2. **Working Group** sessions (concurrent),
3. **Plenary Discussions** based on 1 and 2 above, and
4. **concise reports** (both oral and in poster format) from individual ITEX sites.

Strong emphasis was placed on informal discussions within the Working Groups, and the programme was designed to foster active participation by all delegates. The principal objectives of the Workshop were:

- to review progress made during the NCEAS Synthesis of ITEX Data, Santa Barbara, CA, 4-9 December 1996;
- to evaluate critically the results of the meta-analyses;
- to make a start interpreting the results in mechanistic terms and to use this as a foundation for refining hypotheses and developing new approaches;
- to consider future directions within ITEX and to devise new protocols (for incorporation into updates of the ITEX Manual) where appropriate or necessary.

This document, which has been circulated via the ITEX e-mail list, presents a brief progress report from the meeting (Section 2), written reports from some of the Working Group sessions (Section 3) and a draft protocol for measuring growth rate in bryophytes and lichens (Section 4). The authors of the reports and protocols are identified below, although I have made some minor editorial changes, in places, to ensure that the format is as consistent as possible, without (I hope) changing the emphasis or balance of the individual reports. Comments relating to this summary are welcome so please use the ITEX e-mail lists if you wish to discuss any aspects with the ITEX research community and list subscribers. I have included all the materials submitted to me by 7 October 1997 (Abstracts from posters and oral presentations will appear separately).

My thanks to all the participants in the 8th ITEX Workshop for making it a great success (and for being so patient with some of the logistic problems): please continue the dialogue and debate over the ITEX e-mail list.

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2. Progress:

An enthusiastic team of ITEXers (comprising of Donie Bret-Harte, Laura Gough, Dean Morewood, Kent Schwaegerle, Marilyn Walker and Sarah Woodin), who did not have to rush away immediately after the formal close of the Workshop, stayed behind to draw up a summary statement of the progress made: this is presented below. It should be emphasised at this point, however, that the conclusions relating to the meta-analyses must still be considered preliminary and the analyses on-going. For further information about specific points relating to meta-analysis contact Anna Arft and/or Marilyn Walker on arft@rastro.colorado.edu or mwalker@taimyr.colorado.edu.

1. The meta-analysis has provided sufficient data for preparation of a paper (co-ordinated by Anna Arft), with the main conclusions being:
    - the most consistent effect of the experimental warming treatment was advancement of early season phenology;
    - there is a vegetative growth response that is strongest in the low Arctic and either weak or absent in the high Arctic;
    - there is a minimal and inconsistent reproductive response (in terms of reproductive 'effort' and 'success', but not for flowering phenology; the latter was consistently accelerated in the warming treatments);
    - there are important differences in responses among growth forms;
    - these data represent a relatively short-term transient response and may not be easily extrapolated to predict long-term changes;
    - in many cases the effects of the OTCs relative to natural variation were small.

2. The meta-analysis was used as the basis for discussion of future development of the ITEX programme, with the following recommendations:
    - all sites need community characterisation (detailed point quadrating: see note below);
    - characterising changes in community composition is essential because the response of individuals strongly depends on community composition;
    - biological processes underpinning the trends must be examined in detail, and the ITEX programme should retain the focus on the response of individuals as the building block for integrating physiological, developmental, population and community level processes;
    - overall site characterisation should be improved - e.g. soils, climate (longer-term records) and other species groups and/or trophic levels

(lichens, mosses, fungal fruit bodies, invertebrate and vertebrate herbivores);
- variables to be measured should be assigned an order of priority, based upon their usefulness in meta-analysis, the logistics and effort required to measure them, and the requirements for site-specific data (e.g. for PhD dissertation work);
- measurements of some facets of vegetative growth require further critical evaluation and revision where necessary;
- the biological meaning of 'reproductive growth', and the key variables used to assess it, should be considered further;
- the meta-analyses should be used as a catalyst for the development of mechanistic hypothesis-testing and novel experimentation;
- recognise that short and long-term responses may differ, and long-term experiments are therefore essential.

3. A "wish list" was developed for 'ITEX II' (the next phase of ITEX):
   - additional replicates for destructive plot sampling for below-ground parameters, chemical analyses and invertebrate sampling;
   - incorporate new expertise into the ITEX network.

4. The dates and venue for the next ITEX Workshop (the 9th) are subject to confirmation, although we propose, at this stage, to meet in East Lansing, Michigan, from 3-9 January 1999. Pat Webber and Bob Hollister will host and organise the workshop. At the Royal Holloway meeting a proposal to conduct the 9th Workshop as a symposium to which non-ITEX scientists will be invited was discussed. The exact format of the workshop, however, and the major themes to be considered in Michigan, remain as flexible as possible: please mail suggestions to the ITEX list to ensure that there is an opportunity to discuss these well in advance of the meeting.

Note: ALL ITEX CORE SITES MUST, AS A BASIC REQUIREMENT FOR DATA INTERPRETATION AND SCALING-UP, PERFORM MEASUREMENTS OF **COMMUNITY COMPOSITION** AS INSTRUCTED IN THE ITEX MANUAL.

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3. Individual Working Group Reports:

Meta-analysis - Working Group I:
Rapporteur (and report author): Felix Gugerli; **Chair:** unappointed; **Members:** Matthias Diemer, Ingibjörg Jónsdóttir, Eric Pop, Karl Reiter, Mikael Stenström, Shizuo Suzuki, Jeff Welker.

In this working group we focused on the results from the overall analyses (only separated by treatment years) and on the results with the categorical variables 'azone' (high arctic, low arctic, alpine) or broad and narrow functional type (woody/herbaceous; deciduous, evergreen/forb or graminoid).

Our objectives were (i) to develop broad mechanistic hypotheses, and (ii) to assess whether the data from meta-analysis provided support for such hypotheses and aided in their interpretation.

Hypothesis	Observations	Possible explanations
Phenology accelerated by warming	*leaf bud burst* *flower open* significant response *dispersal* *leaf colour change*: no response	• responding variables seem temperature-dependent • lack of response not necessarily due to inconsistencies among categories, but other biological factors (e.g., deterministic, frost, light-regime, extreme events)
Woody species are more conservative than herbaceous species	*veg. growth*: no effect in woody; strong effect in herbs *repr. growth*: both show effect (stronger in herbs) *repr. effort*: no effect	• leaf size may be more plastic in herbs than in woody species → monitor abundance, not just size • woody species need more time to respond → long-term observations
Vegetative growth responses in the order graminoids > forbs > dec. woody > evegr. woody	but: forbs > graminoids (evergreen > deciduous)	• competition? • allocation to below-ground structures? • short-term effects?
Response stronger at high-arctic (HA) than at low-arctic (LA) or alpine sites	*veg. growth*: almost no effect in HA; strong effect in LA (after 1st year); medium effect in alpine *repr. growth*: effect reduced with time in HA; effect increased with time in LA; alpine: strongest effect in 1st year *repr. effort/success*: practically no effect	• lower above-ground competition in HA • different degree of plasticity of species in different zones (see, e.g., Grime's triangle: stress-tolerant vs. competitor) • veg. growth only due to cell elongation? • repr. effort/success influenced by pollinator limitation

Wishes/proposals for further monitoring or with respect to a manuscript about meta-analyses:

- identify functional groups from other than the traditional perspectives (e.g., clonality, storage-capability)
- change the direction of approach: Which species do respond, and what characteristics do these have in common?
- look at some of the old theorems about tundra ecology – support or re-consider them?

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Meta-analysis - Working Group II:

Rapporteur (and report author): Bob Hollister; **Chair:** ∅rjan Totland

This group suggested that, for the purposes of meta-analysis, the weather conditions during any particular year could be categorised, very simply, into two types: above the average temperature and below the average (i.e. 'good' and 'bad'). We also considered that the previous year's weather should be an additional factor in the analyses. After some discussion, however, the group concluded that the adjustment for weather would ideally involve the current year's conditions coupled with those of several previous years and that this would probably involve modelling (and perhaps prove more effort than is useful at this time).

The group then looked at the output from the NCEAS Workshop:

- Phenology was accelerated in the chambers (with the exception of first colour change). The lack of response at the close of the growing season may be because colour change is deterministic (i.e. responsive not to temperature but to day length or changes in light quality).

- There was an increase in reproductive growth in response to the warming treatments. We rejected the knee-jerk criticism that this is simply etiolation due to reduced wind speeds (or to shading) by pointing to similarities between OTC responses in cool years and controls in warm years (thus emphasising the need to maintain monitoring over several growing seasons within ITEX if possible). We agreed that there were three lines of evidence that show that increased reproductive growth was a result of temperature increase: the results of our short-term manipulations with OTCs, spatial differences due to micro-climate and regional climate, and year-to-year variability. We also concluded that the trend in reproductive growth over the first three years in the High Arctic appeared to be different and that this should be explored.

- The broad original assumption (or hypothesis) that the High Arctic vascular plants should respond more to warming that the Low Arctic is not supported by the meta-analyses. We proposed that actual leaf temperatures, even in the High Arctic, may not be limiting in comparison with other factors, such as moisture or nutrient availability.

The group then went on to consider the 'uncoupling' of canopy and soil temperatures that sometimes occurs in the OTCs. The chambers do not always warm the soil, due to factors such as the size of the plots (and lateral heat fluxes), the effects of restricted air mixing within the OTCs, the canopy type (cover) and soil properties. This uncoupling of air and soil temperatures could be a major limitation of the chambers and may need to be accounted-for in our analyses (including the meta-analyses).

ITEX response variables are also currently restricted in terms of quantifying vegetative reproduction and proliferation. This was seen as a significant limitation, especially bearing in mind the paradigm of strong dependence of the Arctic (and, to a lesser extent, alpine) flora on vegetative reproduction. We suggest several criteria should be used when modifying our variable lists: thus, (i) variables should be important to ITEX as a whole even if they do not appear to be pertinent at some individual sites, (ii) just because we have already measured a response variable in the past does not justify retaining that measure if a more suitable alternative exists, or if the measurement is of limited value, (iii) the time investments and costs are important, and (iii) the variables should, as far as possible, be consistent across sites.

We concluded this working group with some cautionary comments about the meta-analyses. We must examine each analysis by taking a detailed look at the sites, species and variables that the analysis is based upon in order to ensure that the conclusions we make are consistent with our knowledge of the system and that results are not misinterpreted due to cryptic errors in the analysis.

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Meta-analysis - Working Group III:

Rapporteur (and report author): Anna Stenström; **Chair:** Matthias Diemer; **Members:** Felix Gugerli, Annika Jägerbrand, Gaku Kudo, Borgthor Magnusson, Richard Ring, Marilyn Walker, Pat Webber

We discussed the meta-analysis results and came to the following conclusions.

Positive (things working well)

- This is a great study of the biology of global change.
- We show that species-level responses can be scaled-up to the level of growth forms or functional groups.
- This is a new way of using meta-analysis.

Problems and new ideas

- 'Genetics': instead of some narrow functional groups we can maybe use clonality / non-clonality, or the inconsistency of variance, as criteria for further analysis.
- 'Space': should we consider devising an integrated variable for soil and community-data? We also have to differentiate between weather and climate and

we really need long term climate data (although this might be difficult to obtain at all sites): Young's floristic zones also need climate data, not weather data.

- 'Time': we could possibly use weather data to see if we get the same responses in a 'warm' year as in a 'cold' year. But that is a new analysis to be made later. We could also divide the data set after the Chapman & Walsh map.

Some more thoughts

- How 'representative' are our species, sites and functional groups?
- How many species do we have in each family and functional group (i.e. are our comparisons 'balanced')?
- Is there a stronger trend in flowering and reproduction than in vegetative growth?
- The 'year 4 effect' (i.e. the observation of clearer or 'new' response patterns in the 4th year of treatment) needs to be based on observations from more sites (at present it is based on only 1-3 sites, depending on the response variables analysed).
- Could we use bare (unvegetated) ground as an indicator of the intensity of competition?
- Is there a greater vegetative growth response in high-competition environments?
- Do certain functional groups invest in reproduction instead of growth in response to warming?
- Could we interpret narrow functional types in terms of nutrient use patterns?
- Are reproductive and vegetative growth more responsive than reproductive effort and success?

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Meta-analysis - Working Group IV:

Rapporteur (and report author): Ørjan Totland; **Chair:** Greg Henry; **Members:** Gaku Kudo, Volodya Razzhivin, Karl Reiter, Anna Stenstøm, Ørjan Totland

We decided that our tasks were: i) to distil the data presentation (e.g. the quantity of graphs) to a number consistent with publication in a journal article, and ii) to interpret the data presented.

1. Data reduction:

a) Site type vs. high-, low-arctic, alpine: we recommend to remove the site type classification because it is partly redundant with high-, low-arctic and alpine. Site type is also not entirely representative for each site. Detailed climate data from each site should be used instead, in combination with high-, low arctic and alpine.

b) We found site type precipitation very useful.

c) Remove secondary graphs (e.g. Herbaceous divided into forbs and graminoids) if they do not add anything to the results presented in the primary graph (e.g. herbaceous).

d) Remove 'redundant' variables if they show similar results.

e) Remove family level responses from the main paper: present these in a subsequent paper.

f) Remove guerrilla/phalanx classification. These are strategies that only apply to clonal plants. We suggest, instead, to use a clonal/non-clonal classification of species.

g) We suggest that summer thawing degree days TDDs are replaced by the July mean temperature instead. TDDs may be redundant (in the view of this Working Group), and July mean temperature is more readily understandable than thawing degree days.

h) In general we suggest to condense or remove 'redundant' variables when similar responses are found.

i) The breaking-up of some of the variables needs to be justified, because results may be dependent on the break-point.

Brief interpretation of results:

a) Phenology accelerated in the OTCs, but termination of the growing season (senescence) appears fixed. Warming speeds-up phenology and there is great phenotypic plasticity. There are obvious advantages to start growth/flowering early in the thaw period. Termination of growth, however, is not delayed in the OTCs because there may be diminishing 'returns' (e.g. if an economic analogy is used) with prolonged growth coupled with an increased risk of frost damage late in the season.

b) Effects of warming on vegetative growth decrease over experimental time, whereas effects on reproduction increase over time. It appears that a shift in resource allocation from growth to reproduction occurs under warmed conditions. However, there are many limitations in the data: i) small, insignificant, differences across years, ii) fourth year poorly represented, and iii) lack of independence between years.

c) Small effects of warming on vegetative growth at high arctic sites. It may be that plants are constrained from responding to increased temperature if other factors, such as nutrient availability, limit growth. It could also be that high arctic species have a more conservative growth strategy because of high mortality risks associated with increased growth.

d) A precipitation class < 50 mm includes mainly studies from high arctic sites. Thus it may be difficult to isolate the effects of severe conditions and little precipitation.

e) We believe that the small growth response in woody plants is mainly caused by the opposing effects of warming on deciduous and evergreen species. When comparing these groups, and others as well, it is important to know which growth parameters have been measured for each species, since the result may depend on whether, for example, leaf number or leaf size have been measured.

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Summary of Working Group to discuss expanding ITEX and consider additional trophic levels

Rapporteur (and report author): Laura Gough; **Chair:** Phil Wookey; **Group Members:** Gabriele Broll, Peter Crittenden, Annika Jägerbrand, Borgthór Magnússon, Wm. Dean Morewood, Ulf Molau, Steve Oberbauer, Tom Powers, Richard Ring, Gus Shaver & Sarah Woodin

This group spent most of the afternoon discussing additional measurements that need to be made at each site to better characterise the site and measurements that could be added for 'ITEX II'. Throughout the Workshop the importance of classifying sites by soil characteristics was emphasised. We discussed adding three baseline measurements to the ITEX Manual to be conducted at all sites and used in the meta-analysis: (1) pH, (2) bulk density, and (3) thickness of organic/peat layer. Gabriele Broll has been preparing a protocol for the Manual and this is being considered prior to formal adoption (the draft form, which is available upon request - brollg@uni-muenster.de - is also worth consulting). In addition, N mineralisation protocols will be added to the Manual so that site personnel wishing to conduct these measurements would follow a standardised procedure. Gabriele suggested classifying the soil types at each site and will obtain information on soils in the region at an international meeting of soil scientists later this year.

To address additional trophic levels Richard Ring will co-ordinate a small group to devise a sampling protocol for insects and Tom Powers will do the same for nematodes. Annika Jägerbrand, Ingibjörg S. Jónsdóttir and Peter Crittenden have written a protocol for more detailed measurements of growth rates in bryophytes and lichens (this has already been circulated on the ITEX list and reproduced below). Several suggestions were made to increase our understanding of vascular plant response, including recording tiller or meristem density in the plots.

It is generally agreed that the ITEX experiments should be maintained as long as possible in order to obtain good long-term data. As ITEX expands it is important that a procedure for integrating new sites and investigators be developed: we had several new people at the Workshop who found it difficult to determine their role within the ITEX network. This will require more consideration in the future.

Destructive plots are desperately needed in order to sample adequately soils and soil fauna. If destructive plots were available additional measurements could be made including: root phenology, mycorrhizal characterisation, buried bags (for N, and possibly N and P, mineralization studies), moss physiology, lichen lysimeters and further soil description. In planning for ITEX II, the sample area must be increased either by increasing the number of replicates or increasing the size of chambers.

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4. Preliminary protocol (for subsequent adoption in the ITEX Manual)

Reproduced below is the protocol developed by Ingibjörg S. Jónsdóttir, Peter Crittenden and Annika Jägerbrand for bryophyte and lichen studies within the ITEX programme. I have included it here because I believe that this protocol could be added to the ITEX Manual with little or no amendment (I would, however, value some feedback on this from ITEXers, so please use the ITEX lists to make any views you have available for consideration; I am sure the authors would also value comment).

Measuring growth rate in bryophytes and lichens

by Ingibjörg S. Jónsdóttir, Peter Crittenden and Annika Jägerbrand

Bryophytes and lichens are important vegetation components in most tundra vegetation types and they may respond either directly to temperature change or indirectly through interaction with vascular plants. It is, therefore, important to include these groups in ITEX-studies at least in those at community level. Although bryophytes and lichens are quite distinct organisms, in many cases they play a comparable role in plant communities and it is thus appropriate to include both groups under the same protocol. This is particularly true for mat forming mosses and lichens with large cover in the bottom layer. Studies have shown that both mat forming mosses and lichens are extremely efficient in immobilising all atmospheric nutrient input making it unavailable for vascular plants (Crittenden 1989; Lee et al. 1987; Jónsdóttir et al. 1995).

We strongly recommend including bryophytes and lichens in studies at ITEX-sites. This can be done at different levels and we provide some detail on measurements at two of them:

1. Community level measurements.
2. Growth rate of individual shoots.

1. **Community level measurements.**

In the ”point framing” analysis that is recommend in the ”Community baseline measurements for ITEX-studies” it is important to record two hits at each point if possible: 1) first hit in the field layer and 2) first hit in the bottom layer (called ”ground surface” in the Community baseline-protocol). If you have mat-forming bryophytes or lichens you should try to record the thickness of the mat. This is done by making one additional recording at each point: the distance from the bottom string intersection to the soil surface underneath the mat. It may be difficult to find the surface for two reasons: first, you have to be careful not to disturb the mat and secondly, the interface between the bryophyte/lichen mat and the soil surface is not always obvious. The thickness of the mat is then calculated as the difference between the distance to the soil surface and the distance to the surface of the mat (”ground surface”). In this way valuable information on the responses of mat thickness to the OTCs can be obtained.

If you find it too difficult or impossible to identify species or higher taxa in the bottom layer even a recording of a ”functional group” will be informative. We suggest the following groups:

- Crustose lichens
- Foliose lichens
- Fruticose lichens
- Thalloid liverworts
- Leafy liverworts
- Acrocarp mosses (erect, ascending), other than *Sphagnum* and Polytrichales.
- Pleurocarp mosses (prostrate, for example *Hylocomium splendens*)
- Semi-prostrate mosses (for example *Racomitrium lanuginosum*)
- *Sphagnum* mosses
- Polytrichales

These groups can also be used in later meta-analysis of responses at the next level.

2. **Growth measurements.**

There are several methods available and different methods are suitable for different functional groups (see above). Clymo (1970) gives a detailed overview of methods used for measuring growth of *Sphagnum* species some of which have also been used for other species. Below we describe some of the methods that have proved most successful or promising in terms of accuracy and labour intensity and we mention one new method (c).

The first three methods (a-c) use reference marks outside the plant, and the two last methods are based on transplantation of plants cut to known length and/or of known mass. Some of the methods (b,d and e) involve removal and replacement of tagged target plants in a moss or lichen mat. In all these methods the target plants may either be placed back directly into the bryophyte/lichen mat or be first placed in a cage. Whether to use cage or not has to be decided from one case to another after evaluating potential disturbances and errors. By using a cage the damage to the "test" plant is minimised.

Especially for lichens, but also for some mosses, pushing a dry plant into, or pulling it out of a lichen/moss mat would do extensive damage. Under method e) there is a description of a cage that can be used for both bryophytes and lichens to decrease risk of such damage. A potential error in using cages is that a physical separation of a moss shoot or lichen thallus from the remainder of the mat can change the micro-climate of the caged plant.

a) *Cranked wire*.

Suitable for various *Sphagnum* species and other dense, mat forming acrocarp or semi-pleurocarp mosses. A number of ca 15-18 cm long stainless steel wires are cranked twice so there will be two vertical sections and one ca 1-2 cm long horizontal section somewhere in the middle. At time zero ($\mathbf{t}_0$) one end is pushed into the mat until the horizontal section is level with the moss shoots, while the free end projects into the air. It is important that the free end is of exact known length. The difference between this length and the portion still above the moss shoots at a given time ($\mathbf{t}_1$) gives the increase in shoot length during a time interval ($\mathbf{t}_1$ - $\mathbf{t}_0$). By measuring the average dry mass of different length increments in a separate study the increase in shoot length during a time interval can be related to the species specific average mass of plant in unit depth to give an estimate of increase in dry mass. *Advantages* of the method: an easy-to-use and low-disturbance method; non-destructive and so repeated measurements possible; relatively accurate for the right type of mosses provided that many wires are used. *Disadvantages*: difficult to find all wires if not properly marked; risk of disturbance by grazing animals.

b) *Tied thread*.

Suitable for a range of mosses, but preferably mat forming. A thin thread is tied around the stem at a known distance from the apex of a number of shoots that are then placed back into the carpet at time zero ($\mathbf{t}_0$). The shoots are collected at a given time ($\mathbf{t}_1$) and the length increase measured. If the shoots are to be placed back for another time interval an estimate of dry mass increase can be done as in the previous method. If measurements are not to be continued, the dry mass of the new increment can be measured directly. *Advantages*: Suitable for a range of moss growth forms. *Disadvantages*: time consuming; risk of disturbing the moss shoots too much in repeated measurements; difficult to find all shoots if not properly marked.

c) *Fluorescent spray*.

This is a relatively new method that we have not tried, but should be rather accurate for a range of both bryophyte and lichen species forming dense mats (Russel 1988). A layer of fluorescent chemicals is sprayed on the mat at $\mathbf{t}_0$. Shoots are collected at $\mathbf{t}_1$ and the length increment above the fluorescent layer and its dry mass is measured. *Advantages*: low-disturbance method; spraying of the mats can be repeated at intervals without disturbing the mats and at the final harvest the growth could be analysed retrospectively using the different fluourescent layers as markers. *Disadvantages*: there may be a problem finding the right chemicals that will stay in the plant tissue without harming them.

d) *Plants of known length and known mass*.

This method can be used for a range of mat forming mosses, but is probably not suitable for Polytrichales because of the primitive vascular tissue they possess. A number of moss shoots are cut to constant length (ca 5 cm) and weighed (fresh mass). The shoots are divided into two groups, one is tagged and placed back into the moss mat at $\mathbf{t}_0$, while the dry mass is measured in the other half. The ratio average dry mass : fresh mass is used to calculate the dry mass of the transplanted shoots at $\mathbf{t}_0$. The shoots are collected at $\mathbf{t}_1$, their length and weight measured. This method is very similar to the next method which is mainly designed for lichens. While the shoot length of most mosses is easily measured and can be related to dry mass, this is usually impossible to do in most lichen species. The details of the weighing procedure and calculations given under method e) for the lichens can also be followed for mosses. The greatest *advantage* of both these methods is that they are relatively accurate. *Disadvantages* are that there is risk of disturbance and it may be difficult to find transplanted shoots again.

e) *Plants of known mass*

General principle
The dry mass of a lichen is measured at time zero ($\mathbf{t}_0$), the lichen is secured in the field to grow and then dry mass measured again at the end of the growth period ($\mathbf{t}_1$).

Experimental
Test thalli should be selected, trimmed in size if necessary, cleaned of extraneous debris and placed in the field until they dry naturally during a rain-free period. The air dry thalli are then transferred to a laboratory and allowed to equilibrate with laboratory air for *c.*12 h and weighed ($\mathbf{t}_0$) using a 4 decimal place analytical balance. The weighed thalli are tagged for identification purposes and then returned to the field to grow. At the end of the growth period the lichens are recovered, air dried under laboratory conditions, weighed ($\mathbf{t}_1$), oven dried (80 ºC for 12h) and weighed again.

On both occasions ($\mathbf{t}_0$ and $\mathbf{t}_1$) procedures similar to those above are carried out on a duplicate set of "dummy" thalli (but these are not tagged) for which both air dry mass and oven dry mass are determined. The air dry:oven dry mass ratio for dummy thalli is then used to estimate the oven dry mass of the test thalli. Oven dry mass of test thalli at $\mathbf{t}_1$ can then be measured both directly (by drying the test thalli) and indirectly (by using data for dummy thalli): this provides a check on the accuracy of the "dummy" lichen approach.

The suggestion above is that lichen thalli are selected, cleaned etc. in the wet state. This will reduce damage since dry lichens are brittle. It is probably desirable to deviate from natural conditions as little as possible and, thus, to avoid artificially rewetting lichens, especially during periods with strong evaporative forces (e.g. when exposed to strong direct solar radiation). Of course, occasions may arise when there is no other option and spraying with deionized water or simulated rainwater becomes necessary in order to select intact lichen thalli. To avoid errors it is essential that (i) after weighing at $\mathbf{t}_0$ lichen thalli are handled with the greatest of care (e.g. watch-makers forceps) and (ii) thalli are wet when they are recovered from the field at $\mathbf{t}_1$: if thalli in the field are dry on this occasion then they *should* be artificially re-wetted to minimise the likelihood of mechanical damage.

Tags can be made from small pieces of acetate or polyester sheet (e.g. 4 x 3mm) attached to the lichen with polyester thread. I have found it useful to photocopy numbers onto acetate overlays for this purpose. Some lichens (e.g. foliose species) do not lend themselves readily to having things tied to them, instead tags might be tied to their securing mesh (see below).

Securing lichens in the field
Useful materials for this purpose are fine woven stainless steel (s.s.) wire mesh (or fine nylon mesh) and s.s. wire strong enough to be pushed into the soil.

Lichens should be oriented in the field in a manner comparable with undisturbed specimens of the same species. A suggestion for mat-forming species that grow vertically upwards (e.g. species of *Cladonia*, *Stereocaulon*, *Cetraria*) is to construct small cylinders from s.s. mesh which are then inserted into otherwise undisturbed lichen mats thus creating a recess or well. These cylinders should be wide enough to allow air dry thalli to be gently "dropped" into place. It may be desirable to add some material to the bottom of the cylinder to raise the apex of the test thallus to those of the surrounding lichen (suitable material might be dead basal parts of lichen thalli or inert black plastic beads). Foliose lichens (e.g. *Peltigera, Nephroma*) can be placed under fine mesh which is pinned to the soil with s.s. wire. Thalli of *Thamnolia vermicularis* might be held in position using s.s. wire bent like a shepherd's crook.

Relative growth rate

Mean RGR = $(\log_e M_1 - \log_e M_0) / (\mathbf{t}_1 - \mathbf{t}_0)$ (unit mass per unit mass per unit time)

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