Statistical Checklist 4

PLANT GROWTH ANALYSIS

RODERICK HUNT

Institute of Terrestrial Ecology



nvironment Research Council

PLANT GROWTH ANALYSIS

Stating the objectives

- Have you stated clearly and explicitly the objectives of your research and the reasons for
- 2. Have you translated these objectives into precise questions that the research may be expected to answer?

Relevance of plant growth analysis

- 3. Is your research expected to involve plant growth or decay, ie irreversible change in size or shape (however measured), or change in number?
- 4. Do the questions you are asking require more detailed answers on plant form and function than would be available from studies in the fields of production ecology or plant demography?
- 5. Do the questions you are asking require more broadly-based answers on plant form and function than would be available from studies in the field of environmental physiology?
- 6. In particular, do you require an integrated assessment of the performance of whole organs, individuals, populations or communities?
- 7. Do you require this assessment to be made across ecologically- or agronomically-meaningful periods of time?
- 8. Would it be useful to you to express plant performance in terms of derivates which are independent of the size of the system under study?
- 9. Are any of the standard types of derivate in plant growth analysis useful to you either per se or as synthetic or comparative tools? For two generalized plant variates, y and z, and for time t, the commonest derivates are:

absolute growth rates : dv/dt

relative growth rates =: (1/y) (dy/dt)

simple ratios

: z/v

compounded rates

: (I/z) (dy/dt)

integral durations

10. Are interrelationships between these derivates in the form of economic analogies likely to be

For example: $(I/v) \{dv/dt\} =$

 $\times (1/z) (dv/dt)$

(efficiency)

(manpower) × (manpower productivity).

Choice of approach

- 11. Are you interested only in the net or final results of growth or decay over a longish period of
- 12. Are you interested in the detailed time-course of growth or-decay, but know enough about this already to need only the level of definition provided by infrequent sampling?
- 13. If the answer to 11 or 12 is 'yes', can you settle for the classical approach to plant growth analysis, in which mean values of derivates are obtained for the harvest-intervals between large, relatively infrequent samples?
- 14. Are you unable to accept the assumptions implicit in the use of the classical harvest interval formulae (in particular, the problems of assembling accurate interrelationships as in 10)?..

- 15. Do you know little or nothing about the time-course of the growth or decay you wish to study?
- 16. Do you require the most detailed picture possible, perhaps because you expect that speciesor treatment-comparisons will be finely balanced?
- 17. If the answer to 14, 15 or 16 is 'yes', can you settle for the *functional approach* to plant growth analysis in which frequent, small harvests supply data for statistical curve-fitting?
- 18. Are any of the following requirements also convincing arguments for the functional approach? Great condensation of primary data; all sampling occasions in use for all comparisons; minimal physical risk or effort per harvest; unequal replication between harvests; unequal harvest intervals; interpolation; smoothing; integral statistical analysis.

Experimental design and sampling

- 19. In general, can you select the right experimental material and use it in such a way as to get down on to paper the best possible data for deriving answers to your original questions?
- 20. Have your read Statistical Checklist 1 on experimental design?
- 21. Have you read Statistical Checklist 2 on sampling?
- 22. Have you read Evans (1972, pp 39-185) on measurement?
- 23. Have you examined the question of destructive versus non-destructive sampling?

Inspection of data

- 24. As plant variability is commonly value-dependent, do you agree that the natural logarithmic transformation, normally necessary for other reasons, also renders the data homoscedastic, with Gaussian distributions within each harvest subset?
- 25. (Rarely) is such a transformation harmful to, or within, any of your data sets?

Computing

- 26. Have you investigated the locally-available computing or calculating facilities to see what possibilities are available?
- 27. Have you read Statistical Checklist 3 on modelling, questions 71-76?
- 28. Have you decided on whether to write your own program, use a library facility or borrow a program from another worker in the field?
- 29. If proceeding with any of 28, can you be sure of obtaining all of the necessary values, derivates and limits from your chosen method?
- 30. Do your computing facilities, as a whole, provide the best possible combination of availability, suitability and turnaround, or must some trade-off of one against another be achieved?

Classical analytical methods

- 31. Have you obtained the appropriate *classical formulae*, perhaps from a source such as Evans (1972) or Hunt (1978)?
- 32. Do you fully understand the assumptions involved in the use of each of these formulae?
- 33. Can you pair your samples satisfactorily across each harvest interval?
- 34. Can you assemble your classical derivates into populations which permit statistical analysis?
- 35. Is there evidence of random instability in your classical derivates or can you genuinely believe what you see?

Functional analytical methods

36. Do you know where, on the continuum between mechanism and empiricism, your modelling (in the form of curve-fitting) is likely to lie?

- 37. If you have firm mechanistic beliefs or hypotheses about the processes underlying the growth or decay that you are studying, can you select or devise a mathematical function which provides a convenient analogue of those processes?
- 38. Can you fit such a function to your data?
- 39. Can you then proceed to the required derivates, with statistical limits if possible?
- 40. If you have no mechanistic beliefs or hypotheses about your system but merely require a suitable statistical approximating function, can you select or devise a mathematical function which provides a convenient representation of your system?
- 41. Can you fit such a function to your data?
- 42. Can you then proceed to the required fitted derivates, with statistical limits if possible?
- 43. Are any of the following functions likely to be of value to you?

(An exponential function is a function fitted to logarithmically-transformed data.)

First-order polynomial exponential : for log-linear ('exponential') growth or decay;

Second-order polynomial exponential: for simply-curving progressions;

: for S-shaped progressions, or those with Third-order polynomial exponential

linearly-changing curvature;

: for complex curves, but beware of unstable High-order polynomial exponentials

derivates and limits;

: asymptotic, but without an inflection; Monomolecular ; asymptotic, with an inflection mid-way; Logistic (autocatalytic) Gompertz : asymptotic, with an early inflection;

: asymptotic, with a variable inflection; Richards.

: chains of simple functions fitted to complex data, Segments

but with 'lumpy' derivates;

: ditto, with smooth derivates, but costly in degrees Running re fit

of freedom:

: specially-joined polynomials, with seamless Splines

derivates and advantageously-treated degrees of

freedom:

: for vast data sets with recurrent internal trends. Time Series Analysis

- 44. Have you closely examined the question of determinate growth and of asymptotic versus non-asymptotic functions?
- 45. If used, have you sought incidental biological relevance in the parameters of the simpler functions listed in 43?
- 46. Have you balanced to your own satisfaction the often conflicting requirements of biological expectation and statistical exactitude?
- 47. Are you aware of the dangers of over-fitting your data?
- 48. Are you aware of the dangers of under-fitting your data?
- 49. Have you used progressions of the derivates as incidental or afternative indications of goodness or suitability of fit?
- 50. For low-order polynomials, is the stepwise principle of any value?
- 51. If it is, can you accept a variety of types of fit within your collection of data sets, or must they all be similarly treated for any reason?

Post-analysis: assessment and presentation

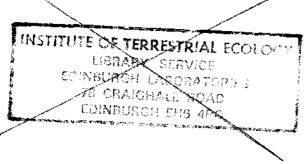
52. Have you applied Occam's razor wherever possible (accepting the simplest of alternative explanations)?

- 53. Has your analysis created a *Procrustean bed* (an abuse of certain data sets in pursuit of over all uniformity)?
- 54. Have you got everything you wanted from the analysis?
- 55. Must you return to another method, perhaps because of the unavailability of meaningful derivates or statistical limits?
- 56. If your derivates are time-based, can you gain additional information by plotting them not against time but against some *other measure of progress*, such as total dry weight?
- 57. Can you incorporate such an alternative measure directly into any of the calculations?
- 58. If you have experimental treatments based not upon multi-state but upon continuous variables, can you incorporate either the primary or derived data into a *response surface* involving independent variables in addition to time?
- 59. If your original design admits both classical and functional methods of analysis, can additional information be gained by performing both?
- 60. Will you present each classical rate-derivate not as single points on a progression in time, but as a histogram with a class-interval equal to the harvest-interval?
- 61. Will you need to present all of the statistical limits calculated for fitted derivates or can economy of presentation be achieved by giving only the 'control', or perhaps the widest, set of limits?
- 62. Can values of derivates from empirical work be used to set values or limits to *state variables* or *rate equations* in subsequent mechanistic work?

The final (and most important) question

63. If you are in any doubt about the purpose of any of the questions in this checklist, should you not obtain some advice from a worker with experience of plant growth analysis before continuing?

There is usually little that an expert advisor can do to help you once you have committed yourself to a faulty approach.



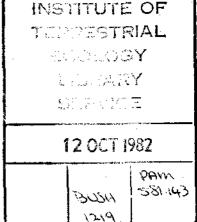
INSTITUTE OF TERRESTRIAL ECOLOGY

LIERARY SERVICE

EDINEUEGE LABORATORIES

BUSH ESTATE, PERICUIK

MIDLOTHIAN EH26 OQB 4



Bibliography

- (Indicating the relevance of each publication in brackets)
- Causton, D. R. (1977) A biologist's mathematics. Edward Arnold, London. (For the mathematics of plant growth.)
- Causton, D. R. & Venus, J. C. (1981) *The biometry of plant growth.* Edward Arnold, London. (For advanced reading on the functional approach: regression theory, asymptotic functions and the growth of plant components.)
- Evans, G. C. (1972) *The quantitative analysis of plant growth.* Blackwell Scientific Publications, Oxford. (For history, experimental technique and advanced reading on the classical approach.)
- Hunt, R. (1978) *Plant growth analysis*. Studies in Biology no. 96. Edward Arnold, London. (For introductory reading on the classical and functional approaches.)
- Hunt, R. (1982) Plant growth curves: a functional approach to plant growth analysis. Edward Arnold, London. (For more advanced reading on the functional approach, rationale, non-asymptotic functions, links with other fields.)
- Jeffers, J. N. R. (1978) *Design of experiments*, (Statistical Checklist 1), Institute of Terrestrial Ecology, Cambridge.
- Jeffers, J. N. R. (1979) Sampling. (Statistical Checklist 2). Institute of Terrestrial Ecology, Cambridge.
- Jeffers, J. N. R. (1980) *Modelling*. (Statistical Checklist 3). Institute of Terrestrial Ecology, Cambridge.
- Thornley, J. H. M. (1976) Mathematical models in plant physiology: a quantitative approach to problems in plant and crop physiology. Academic Press, London. (For mechanistic modelling.)

The Institute of Terrestrial Ecology

THE INSTITUTE OF TERRESTRIAL ECOLOGY (ITE) was established in 1973 as one of the component institutes of the NATURAL ENVIRONMENT RESEARCH COUNCIL.

- The Institute's scientific objectives are: -
 - To improve understanding of the factors determining the structure, composition and processes of ecological systems and the abundance and performance of individual species and organisms.
 - To provide an improved scientific basis for predicting and modelling future trends, especially those resulting from Man's activities, hence permitting a more critical assessment of the need for, and likely benefits of, specific measures to protect and manage the environment.

The results of this research are available to those responsible for the protection, management and wise use of our natural resources. One quarter of ITE's work is research commissioned by customers such as the Department of the Environment, the Countryside Commission and the Nature Conservancy Council. The remainder is fundamental research supported directly by NERC. ITE's expertise is widely used by international organizations in overseas projects and programmes of research.

Statistical Checklists

- 1. This statistical checklist is one of a series currently being developed by the Institute of Terrestrial Ecology (ITE). The aim is to highlight some of the more significant questions to be taken into account in the application of statistical methods to practical research and management. They provide a framework for marshalling thoughts or ideas on the subject, but by their nature cannot expect to cover a subject exhaustively. Wherever possible, references are provided to readily-available textbooks as sources of information for those wishing to follow up any topic in detail.
- Single copies of checklists can be obtained from the Institute of Terrestrial Ecology, 68 Hills Road, Cambridge CB3 1LA, at a cost of 30p, if a stamped addressed envelope is enclosed with your order.
- 3. Bulk supplies are available for institutes and organizations wishing to use these checklists for wider internal circulation. Copies are available in multiples of 20 at £3.00 per pack, post paid.
- 4. The checklists so far issued include:
 - (1) Design of experiments
 - (2) Sampling
 - (3) Modelling
 - (4) Plant growth analysis

Details of new checklists will be announced in the ITE Annual Report.

- ITE welcomes comments and suggestions on the checklists in this series. Please write to the Director, Institute of Terrestrial Ecology, Merlewood Research Station, Grange-over-Sands, Cumbria, LA116JU.
- 6. The help of Mr J. N. R. Jeffers and Dr D. R. Causton is gratefully acknowledged.
- The author is a member of one of ITE's sister institutes, the Unit of Comparative Plant Ecology at the University of Sheffield.

© Copyright 1982

ISBN 0 904282 66 X

Printed by The Lavenham Press Limited, Lavenham, Suffolk, England.