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| **BIOMETRIC TECHNIQUES IN TAXONOMY & SYSTEMATICS**  *Course Organiser: Prof Norman MacLeod, The Natural History Museum, London* |

Organisms are characterized by many patterns of similarity and difference. Biological systematics involves the study of these patterns and use of the results of such studies to test hypotheses in taxonomy, phylogeny, evolution, biogeography, ecology, behaviour, etc. The quantitative study of biological data is variously termed biometrics or, in a strictly systematic context, phenetics. Biometric approaches to systematics are becoming increasingly popular, especially in terms of the geometric assessment of morphological variation.

**Aims**

This short course will deal with the theory and practice of a wide range of biometric techniques including the use of descriptive statistics, regression models, multivariate methods (e.g., principal components analysis, linear discriminant methods), and geometric morphometrics. Emphasis will be placed on methods that can be used to characterize morphological variation, especially the study of the relation between size and shape (= allometry). Students will become familiar with the concepts involved in the use of such methods, interpretation of results, and the operation of simple software packages designed to implement basic data-analysis techniques.

**Objectives**

* Recognize situations in which ordination techniques can be used to answer systematic questions in species identification, functional morphology, ecology, and biogeography.
* Acquire a knowledge of image analysis-image processing techniques sufficient to extract landmark and boundary-coordinate data from images of biological objects.
* Acquire a qualitative-procedural knowledge of the following ordination techniques as they are applied to biological data: regression analysis, principal component analysis (PCA) and Procrustes PCA.
* Understand the relation between morphometric and phylogenetic approaches to biological data analysis.

**Contact information**

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| **Course Schedule** | | |
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| Day | Time | Topic |
| Week 1 |  |  |
| Tuesday, 3 June | 18:00 - 19:00 | Introduction  Biometric Analysis in Taxonomy & Systematics |
|  | 19:00 - 21:00 | Data Collection in Biometry |
| Thursday, 5 June | 18:00 - 19:00 | Allometry |
|  | 19:00 - 21:00 | Allometric Analysis via Linear Regression |
| Saturday, 7 June | 9:30-10:30 | Lab Practical: Data Collection |
|  | 10:30-11:30 | Lab Practical: Allometric Regression |
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| Week 2 |  |  |
| Tuesday, 10 June | 18:00 - 19:00 | Principal Components Analysis (PCA) |
|  | 19:00 - 21:00 | Allometric Analysis via PCA |
| Thursday, 12 June | 18:00 - 19:00 | Geometric Morphometrics&Procrustes PCA |
|  | 19:00 - 21:00 | Allometric Analysis via Procrustes PCA |
| Saturday, 14 June | 9:30-10:30 | Lab Practical: Allometric Analysis via PCA |
|  | 10:30-11:30 | Lab Practical: Allometric Analysis via Procrustes PCA |

**Lecture and Practical Synopses**

**WEEK 1**

**Tuesday, 3 June**

Lecture 1A Introduction to the module

This lecture is intended as an orientation for the students to the general topics, rationale, schedule, structure, assignments, and expectations of the module. In particular, module resources available on the intranet will be discussed as well as the computer skills required for accessing those resources, data, and information. The goal of this presentation is to (1) provide the student with a general understanding of why ordination are important to the study of systematics and (2) provide a clear statement of the assignments and what the student is expected to do in order to master the material presented.

Lecture 1B Biometrics in systematics

This lecture is intended as a historical overview of the use quantitative, biometric, morphometric, and statistical approaches to hypothesis testing in biology. Throughout particular attention will be paid to the manner in which to properly construct an analysis of biological data and the role of ordination in conducting biological hypothesis tests. Goals of these lectures will be for the student to (1) develop an appreciation of the fact that the application of quantitative methods has been part of the corpus of biology and systematics from the very beginnings of these subjects and (2) understand how various mathematical methods have their roots in attempts to address biological research problems.

Lecture 2 Morphometric data-collection theory & software

This presentation will constitute a lecture-demonstration of a series of alternative morphological data acquisition software systems. Students will be encouraged to explore the capabilities of each system on a selection of example systematic images. In particular, the presentation will explain how to use supplied software to record scaled *x,y* coordinate locations of landmarks and linear distances. The goals of this lecture are to (1) familiarize the student with an advanced image analysis/morphological data collection systems, and (2) enable the student to gain confidence in accessing and measuring images of biological specimens.

**Thursday, 5 June**

Lecture 1 Allometry

This lecture will introduce the students to the concept of allometry, the analysis of the effects of size variation on other parameters of biological interest. A detailed discussion of covariance between size adshape will serve to make the general allometric concept plain as well as exploring conceptual differences between the ideas of size and shape. The lecture will also show how such concepts can be investigated using quantitative methods and how the use of ordination techniques can help both in the formulation of specific biological hypotheses to test as well as in testing them. Goals for this lecture include (1) understanding of the difference between size and shape (relative size), (2) understanding of the different types of allometry, (3) understanding the analytic implications and advantages of parsing biometric data across groups (= horizontal) and within groups (= vertical) structures, and (4) understanding how quantitative methods can be used to test the predictions of qualitatively-formulated biological hypotheses.

Reference

LaBarbera, M. 1989. Analyzing body size as a factor in ecology and evolution. Annual Review of Ecology and Systematics 20:97–117.

Lecture 2 Allometryanalysis using bivariate linear regression

This presentation/demonstration will serve to introduce the student to the method of bivariate regression. Various regression models (e.g., least squares, reduced major axis, major axis) will be discussed as well as techniques for estimating the statistical significance of regression results as these apply to allometric studies. Goals include (1) understanding of the importance of choosing a correct numerical model in biometric ordination studies, (2) interpretation of regression results, (3) understanding various strategies for assessing the goodness-of-fit between the regression model and the data.

References

MacLeod, N. 2004.Prospectus & Regressions 1.Palaeontological Association Newsletter 55:28–36.

MacLeod, N. 2004.Regression 2. The Palaeontological Association Newsletter 56:60–71.

**Saturday, 7 June**

Lab Practical Morphometric data collection exercise

This exercise will require that the student collect landmark data from a series of digital images of mammalian carnivores and transform his/her landmark data into a series of Euclidean distances that will be used in subsequent analyses.

Lab Practical Bivariate allometry exercise

This exercise will require that the student use their linear distance data as input into a regression-based allometric analysis. Results will then be used to (1) identify the presence of allometry in their measurements, (2) map regions of the morphology over which allometric relations are similar and different, (3) summarize broad patterns of allometric variation in the sample, and (4) interpret these patterns within both geometric and systematic contexts.

**WEEK 2**

**Tuesday, 10 June**

Lecture 1 Principal components analysis (PCA)

This lecture will introduce the student to the most widely used family of ordination methods; principal component analysis (PCA). While not intended as a mathematical treatment of this topic, the concepts inherent in PCA will be presented with reference to models of multivariate allometry (in order to establish continuity with previous discussions) before engaging issues unique to the PCA approach. In addition, care will be taken to describe practical situations best treated via bivariate and multivariate approaches. Goals for this lecture include (1) understanding of the basic geometric principles of PCA ,(2) understanding how PCA provides a way of extending bivariate regression analysis to multivariate data, and (3) understanding how PCA can be used to analyze allometry.

References

MacLeod, N. 2005.Principal components analysis (eigenanalysis& regression 5).Palaeontological Association Newsletter 59:42–54.

Somers, K. M. 1986. Multivariate allometry and removal of size with principal components analysis. Systematic Zoology 35(3):359–368.

Lecture 2 Analyzing multivariate allometry using PCA

This lecture will focus specifically on the use of PCA to analyse the multivariate allometry of the carnivore skull dataset and will include presentation and discussion of results obtained from the lecturer’s own analysis of this material.

**Thursday, 12 June**

Lecture 1 Landmarks, shape coordinates &*Procrustes* superposition

This lecture will introduce the student to the underlying rationale of landmark-based morphometrics. After a brief, historical introduction the concept of a *landmark* will be introduced. A classification of landmarks will then be developed along with a discussion of the manner in which landmarks relate to the concepts of biological and geometric similarity. The sorts of information that can be provided by landmarks will then be emphasized and contrasted with the sorts of information provided by linear (inter-landmark) distances. Finally, the concept of shape coordinates will be introduced and used to develop a model of allometric shape change using landmark data. Goals of this lecture include (1) understanding what landmarks are and how they should be used in a morphometric analysis, (2) understanding how the characterization of form variation via landmarks is superior to description via linear distances, and (3) understanding how landmark coordinates can be used as the basis of a more geometric approach to form analysis.

References

MacLeod, N. 2008. Size and shape coordinates. Palaeontological Association Newsletter 69:26–36.

MacLeod, N. 2009. Who is *Procrustes* and what has he done with my data? Palaeontological Association Newsletter 70:21–36.

Lecture 2 Analyzing multivariate allometry using Procrustes PCA

This lecture will focus specifically on the use of Procrustes PCA to analyse the multivariate allometry of the carnivore skull dataset and will include presentation and discussion of results obtained from the lecturer’s own analysis of this material.

**Saturday, 14 June**

Lab Practical PCA allometry exercise

This exercise will give the student the opportunity to use their linear distance data as input into a PCA analysis. Results will then be used to (1) identify the presence of multivariate allometry in their measurements, (2) map regions of the morphology over which allometric relations are similar and different, (3) summarize broad patterns of allometric variation in the sample, (4) interpret these patterns within both geometric and systematic contexts, and (5) compare and contrasts results obtained from univariate and multivariate allometric analyses.

Lab Practical Practical: *Procrustes* PCA exercise

This exercise will require that the student use their landmark data as input into a *Procrustes* PCA or tps/RelW analysis (results will be equivalent). Results will then be used to (1) identify the presence of multivariate allometry in their landmark data, (2) map regions of the morphology over which allometric relations are similar and different, (3) summarize broad patterns of allometric variation in the sample, (4) interpret these patterns within both geometric and systematic contexts, and (5) compare and contrasts results obtained from univariate and multivariate allometric analyses.