

Appendix 2: Principal literature sources and further reading

A list of some of the core methods papers was given in the Introduction, and the source papers for the data used in examples can be found in Appendix 1. Here we itemize, for each chapter, the source of analyses which repeat those in published literature, and where figures have been redrawn from. Figures or analyses not mentioned can be assumed to originate with this publication. Also sometimes mentioned are historical references to earlier developments of the ideas in that chapter, or other useful background reading.

Chapter 1: Framework. The categorisation here is an extension of that given by [Warwick \(1988a\)](#) . The Frierfjord macrofauna data and analyses (Tables 1.2 & 1.6 and Figs. 1.1, 1.2 & 1.7) are extracted and re-drawn from [Bayne, Clarke & Gray \(1988\)](#) , [Gray, Aschan, Carr *et al.* \(1988\)](#) and [Clarke & Green \(1988\)](#) , the Loch Linnhe macrofauna data (Table 1.4 and Fig. 1.3) from [Pearson \(1975\)](#) , and the ABC curves (Fig. 1.4) from [Warwick \(1986\)](#) . The species abundance distribution for Garroch Head macrofauna (Fig. 1.6) is first found in [Pearson, Gray & Johannessen \(1983\)](#) , and the multivariate linking to environmental variables (Fig. 1.11) in [Clarke & Ainsworth \(1993\)](#) . The 'coherent species curves' (Fig. 1.10) for the Loch Linnhe data are redrawn from [Somerfield & Clarke \(2013\)](#) . The mesocosm data from the nutrient enrichment experiment (Table 1.7) and the MDS plot for copepods and nematodes (Fig. 1.12) are extracted and redrawn from [Gee, Warwick, Schaanning *et al.* \(1985\)](#) .

Chapters 2 and 3: Similarity and clustering. These methods originated in the 1950's and 60's (e.g. [Florek, Lukaszewicz, Perkal *et al.* \(1951\)](#) ; [Sneath \(1957\)](#) ; [Lance & Williams \(1967\)](#)). The description here widens that of [Field, Clarke & Warwick \(1982\)](#) , with some points taken from the general texts of [Everitt \(1980\)](#) and [Cormack \(1971\)](#) . The dendrogram of Frierfjord macrofaunal samples (Fig.3.1) is redrawn from [Gray, Aschan, Carr *et al.* \(1988\)](#) , and the zooplankton example (Figs. 3.2 & 3.3) from [Collins & Williams \(1982\)](#) . The SIMPROF test for samples on agglomerative clusters is described in [Clarke, Somerfield & Gorley \(2008\)](#) ; Fig. 3.8 mimics one in [Anderson, Gorley & Clarke \(2008\)](#) , and the other cluster methods (unconstrained divisive and k-R clustering, maximising R) are somewhat new to this publication.

Chapter 4: Ordination by PCA. This is a founding technique of multivariate statistics, see for example [Chatfield & Collins \(1980\)](#) and [Everitt \(1978\)](#) . The MDS from a dosing experiment in the Solbergstrand mesocosms (Fig. 4.2) is from [Warwick, Carr, Clarke *et al.* \(1988\)](#) .

Chapter 5: Ordination by MDS. Non-metric MDS was introduced by [Shepard \(1962\)](#) and [Kruskal \(1964\)](#) ; two standard texts are [Kruskal & Wish \(1978\)](#) and [Schiffman, Reynolds & Young \(1981\)](#) . Here, the exposition parallels that in [Field, Clarke & Warwick \(1982\)](#) and [Clarke \(1993\)](#) ; the Exe nematode graphs (Figs. 5.1, 5.2, 5.4, 5.5) are redrawn from the former. The dosing experiment (Fig. 5.6) is discussed in [Warwick, Carr, Clarke *et al.* \(1988\)](#) . Metric MDS (see [Cox & Cox \(2001\)](#)), not to be confused with the similar, but not identical, PCO ordinations (produced by PERMANOVA+ for example), was also an early introduction but is much less commonly implemented in software. The combining of nMDS and mMDS stress functions bears some relationship to hybrid and semi-strong hybrid scaling methods ([Faith, Minchin & Belbin \(1987\)](#) , [Belbin \(1991\)](#)) but with some important differences in implementation and with a different rationale here (the avoidance of collapsed sub-groups in an MDS plot, and for two nMDS stress functions, the merging of similarities of different types); see footnote on [page 5.8](#).

Chapter 6: Testing. The basic permutation test and simulation of significance levels can be traced to [Mantel \(1967\)](#) and [Hope \(1968\)](#) , respectively. In this context (e.g. Figs. 6.2 & 6.3 and eqt. 6.1) it is described by [Clarke & Green \(1988\)](#) . A fuller discussion of the extension to 2-way nested and crossed ANOSIM tests (including Figs. 6.4 & 6.6) is in [Clarke \(1993\)](#) (with some asymptotic results in [Clarke \(1988\)](#)); the coral analysis (Fig. 6.5) is in [Warwick, Clarke & Suharsono \(1990\)](#) , and the Tasmanian meiofaunal MDS (Fig. 6.7) in [Warwick, Clarke & Gee \(1990\)](#) . The 2-way design without replication (Figs. 6.8-6.12) is tackled in [Clarke & Warwick \(1994\)](#) ; see also [Austen & Warwick \(1995\)](#) . The ordered ANOSIM test is new to this publication, as are the extensions to 3-way crossed/nested designs. [Lek, Fairclough, Platell *et al.* \(2011\)](#) give the 'flattened' 2-way ANOSIM tests for the 3-way crossed example of labrid diets; Fig. 6.15 is redrawn from there. The NZ kelp holdfast data is provided with the PERMANOVA+ software ([Anderson, Gorley & Clarke \(2008\)](#)). Fig. 6.17 is partly extracted from [Warwick, Ashman, Brown *et al.* \(2002\)](#) .

Chapter 7: Species analyses. Clustering on species similarities is given in [Field, Clarke & Warwick \(1982\)](#) for the Exe nematode data; see also [Clifford & Stephenson \(1975\)](#) . SIMPROF test for species ('coherent curves') follows [Somerfield & Clarke \(2013\)](#) ; Figs. 7.1-7.6 are redrawn from there. Shade plots are described in [Clarke, Tweedley & Valesini \(2014\)](#) but have a very long history (see [Wilkinson & Friendly \(2008\)](#)), though there are some novelties in the options outlined here, in terms of combinations of input data, axis ordering, cluster analysis choices, and so on. The SIMPER (similarity percentages) procedure is given in [Clarke \(1993\)](#) , and the 2-way crossed SIMPER first used in [Platell, Potter & Clarke \(1998\)](#) . Simple bubble plots are a staple routine for graphical output but PRIMER 7's segmented bubble plots were first used in [Stoffels, Clarke, Rehwinkel *et al.* \(2014\)](#) and in [Purcell, Rushworth, Clarke *et al.* \(2014\)](#) .

Chapter 8: Univariate/graphical analyses. [Pielou \(1975\)](#) , [Heip, Herman & Soetaert \(1988\)](#)

and [Magurran \(1991\)](#) are useful texts, summarising a large literature on a variety of diversity indices and ranked species abundance plots. The diversity examples here (Figs. 8.1 & 8.2) are discussed by [Warwick, Platt, Clarke *et al.* \(1990\)](#) and [Warwick, Clarke & Suharsono \(1990\)](#) respectively, and the Caswell V computations (Table 8.1) are from [Warwick, Platt, Clarke *et al.* \(1990\)](#) . The Garroch Head species abundance distributions (Fig. 8.4) are first found in [Pearson, Gray & Johannessen \(1983\)](#) ; Fig. 8.3 is redrawn from [Pearson & Blackstock \(1984\)](#) . [Warwick \(1986\)](#) introduced Abundance–Biomass Comparison curves, and the Loch Linnhe and Garroch Head illustrations (Figs. 8.7 & 8.8) are redrawn from [Warwick \(1986\)](#) and [Warwick, Pearson & Ruswahyuni \(1987\)](#) . The transformed scale and partial dominance curves of Figs. 8.9-8.11 were suggested by [Clarke \(1990\)](#) , which paper also tackles issues of summary statistics (Fig. 8.12, equation 8.7, and as employed in Fig. 8.13) and significance tests for dominance curves (the DOMDIS routine in PRIMER). Use of ANOSIM on distances among curves (growth curves, particle size distributions etc) has been advocated at PRIMER courses for some years and there are now a few examples in the literature. Similarly, the treatment of multiple diversity indices by multivariate methods, to ascertain the true (and limited) dimensionality of information captured, and the consistent (mechanistic) relationships between indices seen in ordination patterns (such as Fig. 8.16), has long been a staple of PRIMER courses, though never specifically published.

Chapter 9: Transformations. The chapter start is an expansion of the discussion in [Clarke & Green \(1988\)](#) ; Fig. 9.1 is recomputed from [Warwick, Carr, Clarke *et al.* \(1988\)](#) . Detailed description of dispersion weighting (DW) is in [Clarke, Chapman, Somerfield *et al.* \(2006\)](#) ; Figs. 9.2, 9.4 of the Fal nematode data ([Somerfield, Gee & Warwick \(1994a\)](#) and [Somerfield, Gee & Warwick \(1994b\)](#)) are redrawn from [Clarke, Chapman, Somerfield *et al.* \(2006\)](#) . The use of shade plots to aid transformation or DW choices is the topic of [Clarke, Tweedley & Valesini \(2014\)](#) . A different form of weighting of variables (by their standard deviation) is described in [Hallett, Valesini & Clarke \(2012\)](#) .

Chapter 10: Aggregation. This description of the effects of changing taxonomic level is based on [Warwick \(1988b\)](#) , from which Figs. 10.2-10.4 and 10.7 are redrawn. Fig. 10.1 is discussed in [Gray, Aschan, Carr *et al.* \(1988\)](#) , Fig. 10.5 and 10.8 in [Warwick, Clarke & Suharsono \(1990\)](#) and Fig. 10.6 in [Gray, Clarke, Warwick *et al.* \(1990\)](#) (or [Warwick & Clarke \(1993a\)](#) , in this categorisation). A methodology for examining the comparative effects on an analysis of choice of taxonomic level (and transform) can be found in [Olsgard, Somerfield & Carr \(1997\)](#) , [Olsgard, Somerfield & Carr \(1998\)](#) , and [Olsgard & Somerfield \(2000\)](#) .

Chapter 11: Linking to environment. For wider reading on this type of ‘canonical’ problem, see Chapter 5 of [Jongman, ter Braak & Tongeren \(1987\)](#) , including [ter Braak \(1986\)](#) 's method of canonical correspondence analysis. The approach here of performing environmental and biotic

analyses separately, and then comparing them, combines that advocated by [Field, Clarke & Warwick \(1982\)](#) : superimposing variables on the biotic MDS, and by [Clarke & Ainsworth \(1993\)](#) : the BIO-ENV program. The data in Table 11.1 is from [Pearson & Blackstock \(1984\)](#) . Fig 11.3 is redrawn from [Collins & Williams \(1982\)](#) and Fig. 11.6 from [Field, Clarke & Warwick \(1982\)](#) ; Figs. 11.7, 11.8, 11.10 and Table 11.2 are from [Clarke & Ainsworth \(1993\)](#) . The global BEST test is given in [Clarke, Somerfield & Gorley \(2008\)](#) , as is the description of linkage trees, the general idea of which (as ‘multivariate regression trees’) can be found in [De'Ath \(2002\)](#) . The modification to a constrained (2-way) BEST is new to this publication.

Chapter 12: Community experiments. Influential papers and books on field experiments, and causal interpretation from observational studies in general, include [Connell \(1974\)](#) , [Hurlbert \(1984\)](#) , [Green \(1979\)](#) and many papers by A J Underwood, M G Chapman and collaborators, in particular the [Underwood \(1997\)](#) book. [Underwood & Peterson \(1988\)](#) give some thoughts specifically on mesocosm experiments. Lab-based microcosm experiments on community structure, using this analysis approach, are typified by [Austen & Somerfield \(1997\)](#) and [Schratzberger & Warwick \(1998a\)](#) . Figs. 12.2 and 12.3 are redrawn from [Warwick, Clarke & Gee \(1990\)](#) and Figs. 12.5, 12.6 from [Gee, Warwick, Schaanning *et al.* \(1985\)](#) .

Chapter 13: Data requirements. The exposition parallels that in [Warwick \(1993\)](#) but with additional examples. Figs. 13.1-13.3 and 13.8 are redrawn from [Warwick \(1993\)](#) , and earlier found in [Colebrook \(1986\)](#) , [Dawson-Shepherd, Warwick, Clarke *et al.* \(1992\)](#) , [Warwick \(1988b\)](#) and [Gray, Aschan, Carr *et al.* \(1988\)](#) respectively. Fig. 13.4 is redrawn from [Warwick, Clarke & Gee \(1990\)](#) , Fig. 13.5 from [Warwick, Platt, Clarke *et al.* \(1990\)](#) , Fig. 13.6 from [Warwick, Clarke & Suharsono \(1990\)](#) and Fig. 13.7 from [Warwick & Clarke \(1991\)](#) .

Chapter 14: Relative sensitivities. This parallels the earlier sections of [Warwick & Clarke \(1991\)](#) , from which all these figures (except Figs. 14.11 & 14.14) have been redrawn. Primary source versions of the figures can be found as follows: Figs. 14.1-14.3, [Gray, Aschan, Carr *et al.* \(1988\)](#) ; Figs. 14.5-14.7, [Warwick, Clarke & Suharsono \(1990\)](#) ; Figs 14.9-14.10, [Dawson-Shepherd, Warwick, Clarke *et al.* \(1992\)](#)); Figs. 14.11-14.12, [Gee & Warwick \(1994a\)](#) and [Gee & Warwick \(1994b\)](#) ; Figs. 14.14-14.16, [Austen & Warwick \(1989\)](#) .

Chapter 15: Multivariate measures of disturbance and relating to models. The first part on multivariate measures of stress follows the format of [Warwick & Clarke \(1995a\)](#) and [Warwick & Clarke \(1995b\)](#) , and is an amalgamation of ideas from three primary papers: [Warwick & Clarke \(1993a\)](#) on ‘meta-analysis’ of NE Atlantic macrobenthic studies, [Warwick & Clarke \(1993b\)](#) on the increase in multivariate dispersion under disturbance, and [Clarke, Warwick & Brown \(1993\)](#) on the breakdown of seriation patterns. Figs. 15.1-15.3 and Table 15.1 are redrawn and extracted from

the first reference, Fig. 15.4 and Table 15.2 from the second and Figs. 15.5 & 15.6 and Table 15.5 from the third. The analysis in Table 15.4 is from [Warwick, Ashman, Brown *et al.* \(2002\)](#) . In the second part, the principle of matrix correlations using a Pearson coefficient dates to [Mantel \(1967\)](#) ; RELATE tests are a non-parametric form. The seriation test with replication is discussed in detail by [Somerfield, Clarke & Olsford \(2002\)](#) , the Tees data is analysed in [Warwick, Ashman, Brown *et al.* \(2002\)](#) , the sea-loch data in [Somerfield & Gage \(2000\)](#) , the Gullfaks Fig. 15.10 is extracted from [Somerfield, Clarke & Olsford \(2002\)](#) and the Leschenault Fig. 15.12 redrawn from [Veale, Tweedley, Clarke *et al.* \(2014\)](#) .

Chapter 16: Further multivariate comparisons and resemblance measures. The general extension of the Bio-Env approach of Chapter 11, to combinations other than selecting environmental variables to match biotic patterns, is described in [Clarke & Warwick \(1998a\)](#) . This details the forward/backward stepping search algorithm BVStep, and uses it to select subsets of 'influential' species from a biotic matrix. Second-stage MDS was defined by [Somerfield & Clarke \(1995\)](#) and early examples of its use can be found in [Olsford, Somerfield & Carr \(1997\)](#) and [Olsford, Somerfield & Carr \(1998\)](#) . Figs. 16.1 to 16.3, and Tables 16.1 and 16.2, are extracted from [Clarke & Warwick \(1998a\)](#) , and Fig. 16.5 from [Somerfield & Clarke \(1995\)](#) . The definition and behaviour of zero-adjusted Bray-Curtis is given by [Clarke, Somerfield & Chapman \(2006\)](#) , and that paper also discusses the relative merits of the resemblance measures covered here and introduces the use of second-stage MDS for comparing coefficients. Figs. 16.7 to 16.10 are a recalculated form of some of the figures of that paper; Fig. 16.11 expands the set of coefficients considered there. The very different use of second-stage analysis to generate 'interaction-type' plots is the subject of . Figs. 16.12 to 16.13 and 16.15 to 16.17 are redrawn from there.

Chapter 17: Taxonomic distinctness measures. [Warwick & Clarke \(1995b\)](#) first defined taxonomic diversity/distinctness. Earlier work, from a conservation perspective, and using different species relatedness properties (such as PD), can be found in, e.g. [Faith \(1992\)](#) , [Faith \(1994\)](#) , [Vane-Wright, Humphries & Williams \(1991\)](#) and [Williams, Humphries & Vane-Wright \(1991\)](#) . The superior sampling properties of average taxonomic distinctness (Δ^+), and its testing structure in the case of simple species lists, are given in [Clarke & Warwick \(1998b\)](#) , and applied to UK nematodes by [Warwick & Clarke \(1998\)](#) and [Clarke & Warwick \(1999\)](#) . Variation in taxonomic distinctness (Λ^+) was introduced, and its sampling properties examined, in [Clarke & Warwick \(2001\)](#) , and a review of the area can be found in [Warwick & Clarke \(2001\)](#) , from which Figs. 17.1, 17.2, 17.5, 17.11, 17.12 are redrawn. Fig. 17.3 is discussed in [Warwick & Clarke \(1995b\)](#) , Fig. 17.4 in [Warwick, Ashman, Brown *et al.* \(2002\)](#) , Figs. 17.6, 17.8, 17.9, 17.14, 17.17 in [Clarke & Warwick \(2001\)](#) , Fig. 17.7 in [Clarke & Warwick \(1998b\)](#) and Figs. 17.10, 17.13 in [Rogers, Clarke & Reynolds \(1999\)](#) . Taxonomic dissimilarities are discussed in [Clarke, Somerfield & Chapman \(2006\)](#) , from which the two examples, Fig. 17.19, 17.20 are taken. The measures were first defined in

[Clarke & Warwick \(1998a\)](#) and [Izsak & Price \(2001\)](#) .

Chapter 18: Bootstrap average regions. Bootstrapping univariate data was introduced by [Efron \(1979\)](#) , see also [Efron & Tibshirani \(1993\)](#) . Its specific application to these complex multivariate contexts is new to this publication and might best be treated as experimental, for the moment. Certainly the nominal region coverage probabilities (e.g. 95%) should not be given a formal 95% confidence region interpretation, since some sources of uncertainty are, inevitably, not included in that probability statement – primarily how well the lower-dimensional region represents the higher-dimensional reality.

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