

Appendices

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A1 Acknowledgements

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A2 References

[Akaike \(1973\)](#)

Akaike H. 1973. 'Information theory as an extension of the maximum likelihood principle', pp. 267-281 in Petrov BN & Caski F (eds). *Proceedings, 2nd International Symposium on Information Theory*. Akademiai Kiado, Budapest.

[Amanieu, Legendre, Troussellier et al. \(1989\)](#)

Amanieu, M., Legendre P., Troussellier M. and Frisoni G.-F. (1989) 'Le programme Écothau: théorie écologique et base de la modélisation', *Oceanologica Acta*, 12, pp. 189-199.

[Anderson \(1935\)](#)

Anderson, E. (1935) 'The irises of the Gaspé peninsula', *Bulletin of the American Iris Society*, 59, pp. 2-5.

[Anderson \(2001a\)](#)

Anderson, M.J. (2001a) 'A new method for non-parametric multivariate analysis of variance', *Austral Ecology*, 26, pp. 32-46.

[Anderson \(2001b\)](#)

Anderson, M.J. (2001b) 'Permutation tests for univariate or multivariate analysis of variance and regression', *Canadian Journal of Fisheries and Aquatic Sciences*, 58, pp. 626-639.

[Anderson \(2006\)](#)

Anderson, M.J. (2006) 'Distance-based tests for homogeneity of multivariate dispersions', *Biometrics*, 62, pp. 245-253.

[Anderson, Diebel, Blom et al. \(2005\)](#)

Anderson, M.J., Diebel, C.E., Blom, W.M. and Landers, T.J. (2005) 'Consistency and variation in kelp holdfast assemblages: spatial patterns of biodiversity for the major phyla at different taxonomic resolutions', *Journal of Experimental Marine Biology and Ecology*, 320, pp. 35-56.

[Anderson, Ellingsen & McArdle \(2006\)](#)

Anderson, M.J., Ellingsen, K.E. and McArdle B.H. (2006) 'Multivariate dispersion as a measure of beta diversity', *Ecology Letters*, 9, pp. 683-693.

[Anderson, Ford, Feary et al. \(2004\)](#)

Anderson, M.J., Ford, R.B., Feary, D.A. and Honeywill, C. (2004) 'Quantitative measures of sedimentation in an estuarine system and its relationship with intertidal soft-sediment infauna', *Marine Ecology-Progress Series*, 272, pp. 33-48.

[Anderson & Gribble \(1998\)](#)

Anderson, M.J. and Gribble N.A. (1998) 'Partitioning the variation among spatial, temporal and environmental components in a multivariate data set', *Australian Journal of Ecology*, 23, pp. 158-167.

[Anderson & Legendre \(1999\)](#)

Anderson, M.J. and Legendre, P. (1999) 'An empirical comparison of permutation methods for tests of partial regression coefficients in a linear model', *Journal of Statistical Computation and Simulation*, 62, pp. 271-303.

[Anderson & Millar \(2004\)](#)

Anderson, M.J. and Millar R.B. (2004) 'Spatial variation and effects of habitat on temperate reef fish assemblages in northeastern New Zealand', *Journal of Experimental Marine Biology and Ecology*, 305, pp. 191-221.

[Anderson, Millar, Blom et al. \(2005\)](#)

Anderson, M.J., Millar, R.B., Blom, W.M. and Diebel, C.E. (2005) 'Nonlinear multivariate models of successional change in community structure using the von Bertalanffy curve', *Oecologia*, 146, pp. 279-286.

[Anderson & Robinson \(2001\)](#)

Anderson, M.J. and Robinson, J. (2001) 'Permutation tests for linear models', *Australian & New Zealand Journal of Statistics*, 43, pp. 75-88.

[Anderson & Robinson \(2003\)](#)

Anderson, M.J. and Robinson, J. (2003) 'Generalized discriminant analysis based on distances', *Australian & New Zealand Journal of Statistics*, 45, pp. 301-318.

[Anderson & ter Braak \(2003\)](#)

Anderson, M.J. and ter Braak, C.J.F. (2003) 'Permutation tests for multi-factorial analysis of variance', *Journal of Statistical Computation and Simulation*, 73, pp. 85-113.

[Anderson & Thompson \(2004\)](#)

Anderson, M.J. and Thompson, A.A. (2004) 'Multivariate control charts for ecological and environmental monitoring', *Ecological Applications*, 14, pp. 1921-1935.

[Anderson & Willis \(2003\)](#)

Anderson, M.J. and Willis, T.J. (2003) 'Canonical analysis of principal coordinates: a useful method of constrained ordination for ecology', *Ecology*, 84, pp. 511-525.

[Andrew & Mapstone \(1987\)](#)

Andrew, N.L. and Mapstone, B.D. (1987) 'Sampling and the description of spatial pattern in marine ecology', *Oceanography and Marine Biology, Annual Review*, 25, pp. 39-90.

[Arrhenius \(1921\)](#)

Arrhenius, O. (1921) 'Species and area', *Journal of Ecology*, 9, pp. 95-99.

[Beck \(1997\)](#)

Beck, M.W. (1997) 'Inference and generality in ecology: current problems and an experimental solution', *Oikos (Copenhagen, Denmark)*, 78, pp. 265-273.

[Blackwell, Brown & Mosteller \(1991\)](#)

Blackwell, T., Brown, C. and Mosteller, F. (1991) 'Which denominator?', in F. Mosteller and J.W. Tukey (eds) *Hoaglin DC*. New York: Fundamentals of exploratory analysis of variance. John Wiley & Sons, pp. 252-294.

[Borcard & Legendre \(1994\)](#)

Borcard, D. and Legendre, P. (1994) 'Environmental control and spatial structure in ecological communities: an example using Oribatid mites (Acari, Oribatei)', *Environmental and Ecological Statistics*, 1, pp. 37-53.

[Borcard, Legendre & Drapeau \(1992\)](#)

Borcard, D., Legendre, P. and Drapeau, P. (1992) 'Partialling out the spatial component of ecological variation', *Ecology*, 73, pp. 1045-1055.

[Box \(1953\)](#)

Box, G.E.P. (1953) 'Non-normality and tests on variances', *Biometrika*, 40, pp. 318-335.

Box (1954)

Box, G.E.P. (1954) 'Some theorems on quadratic forms applied in the study of analysis of variance problems, II Effects of inequality of variance and of correlation between errors in the two-way classification', *Annals of Mathematical Statistics*, 25, pp. 484–498.

Box & Cox (1964)

Box, G.E.P. and Cox, D.R. (1964) 'An analysis of transformations', *Journal of the Royal Statistical Society, Series B*, 26, pp. 211–252.

Bray & Curtis (1957)

Bray, J.R. and Curtis, J.T. (1957) 'An ordination of the upland forest communities of southern Wisconsin', *Ecological Monographs*, 27, pp. 325–349.

Brown (1983)

Brown, B.M. (1983) 'Statistical uses of the spatial median', *Journal of the Royal Statistical Society, Series B*, 45, pp. 25–30.

Brown & Forsythe (1974)

Brown, M.B. and Forsythe, A.B. (1974) 'Robust tests for the equality of variances', *Journal of the American Statistical Association*, 69, pp. 364–376.

Bumpus (1898)

Bumpus, H.C. (1898) 'The elimination of the unfit as illustrated by the introduced sparrow, *Passer domesticus*', *Biological Lectures, Marine Biology Laboratory, Woods Hole, Massachusetts 11th Lecture*, 11, pp. 209–226.

Burnham & Anderson (2002)

Burnham, K.P. and Anderson, D.R. (2002) *Model selection and multi-model inference: a practical information-theoretic approach*, 2nd edition. New York: Springer.

Cade & Richards (1996)

Cade, B.S. and Richards, J.D. (1996) 'Permutation tests for least absolute deviation regression', *Biometrics. Journal of the International Biometric Society*, 52, pp. 886–902.

Cailliez (1983)

Cailliez, F. (1983) 'The analytical solution of the additive constant problem', *Psychometrika*, 48, pp. 305–308.

[Cailliez & Pagès 1976](#)

Cailliez, F. and Pagès, J.-P. (1976) *Introduction à l'analyse des données*. Société de Mathématiques appliquées et de Sciences humaines, Paris.

[Chapman, Underwood & Skilleter \(1995\)](#)

Chapman, M.G., Underwood, A.J. and Skilleter, G.A. (1995) 'Variability at different spatial scales between a subtidal assemblage exposed to the discharge of sewage at two control locations', *Journal of Experimental Marine Biology and Ecology*, 189, pp. 103–122.

[Clarke \(1993\)](#)

Clarke, K.R. (1993) 'Non-parametric multivariate analyses of changes in community structure', *Australian Journal of Ecology*, 18, pp. 117–143.

[Clarke, Chapman, Somerfield et al. \(2006\)](#)

Clarke, K.R., Chapman, M.G., Somerfield, P.J. and Needham, H.R. (2006) 'Dispersion-based weighting of species counts in assemblage analyses', *Marine Ecology Progress Series*, 320, pp. 11–27.

[Clarke & Gorley \(2006\)](#)

Clarke, K.R. and Gorley, R.N. (2006 or 2015) *PRIMER v6 (or v7): User Manual/Tutorial*. Plymouth: PRIMER-E.

[Clarke & Green \(1988\)](#)

Clarke, K.R. and Green, R.H. (1988) 'Statistical design and analysis for a "biological effects" study', *Mar. Ecol. Prog. Ser.*, 46, pp. 213–226.

[Clarke, Somerfield, Airoidi et al. \(2006\)](#)

Clarke, K.R., Somerfield, P.J., Airoidi, L. and Warwick, R.M. (2006) 'Exploring interactions by second-stage community analyses', *Journal of Experimental Marine Biology and Ecology*, 338, pp. 179–192.

[Clarke, Somerfield & Chapman \(2006\)](#)

Clarke, K.R., Somerfield, P.J. and Chapman, M.G. (2006) 'On resemblance measures for ecological studies, including taxonomic dissimilarities and a zero-adjusted Bray-Curtis coefficient for denuded assemblages', *Journal of Experimental Marine Biology and Ecology*, 330, pp. 55–80.

Clarke & Warwick (2001)

Clarke, K.R. and Warwick, R.M. (2001) *Change in marine communities, 2nd edition*. Plymouth: PRIMER-E Ltd.

Cleary, Genner, Boyle *et al.* (2005)

Cleary, D.F.R., Genner, M.J., Boyle T.J.B., Setyawati, T., Angraeti, C.D. and Menken, S.B.J. (2005) 'Associations of bird richness and community composition with local and landscape-scale environmental factors in Borneo', *Landscape Ecology*, 20, pp. 989–1001.

Coleman, Vytopil, Goodsell *et al.* (2007)

Coleman, M.A., Vytopil, E., Goodsell, P.J., Gillanders, B.M. and Connell, S.D. (2007) 'Diversity and depth-related patterns of mobile invertebrates associated with kelp forests', *Marine and Freshwater Research*, 58, pp. 589–595.

Connor & McCoy (1979)

Connor, E.F. and McCoy, E.D. (1979) 'The statistics and biology of the species-area relationship', *American Naturalist*, 113, pp. 791–833.

Conover, Johnson & Johnson (1981)

Conover, W.J., Johnson, M.E. and Johnson, M.M. (1981) 'A comparative study of tests for homogeneity of variances, with applications to the outer continental shelf bidding data', *Technometrics: a journal of statistics for the physical, chemical, and engineering sciences*, 23, pp. 351–361.

Cooper, Green, Norkko *et al.* (1999)

Cooper, A.B., Green, M.O., Norkko, A., Oldman, J.W., Stroud, M.J. and Thrush, S.F. (1999) 'Assessment of sediment impacts on Okura estuary associated with catchment development: synthesis', *Report No ARC*, 9024.

Cornfield & Tukey (1956)

Cornfield, J. and Tukey, J.W. (1956) 'Average values of mean squares in factorials', *Annals of Mathematical Statistics*, 27, pp. 907–949.

Day & Quinn (1989)

Day, R.W. and Quinn, G.P. (1989) 'Comparisons of treatments after an analysis of variance in ecology', *Ecological Monographs*, 59, pp. 433–463.

[Draper, Hodges, Mallows et al. \(1993\)](#)

Draper, D., Hodges, J.S., Mallows, C.L. and Pregibon, D. (1993) 'Exchangeability and data analysis', *Journal of the Royal Statistical Society, Series A*, 156, pp. 9–37.

[Dutilleul, Stockwell, Frigon et al. \(2000\)](#)

Dutilleul, P., Stockwell, J.D., Frigon, D. and Legendre, P. (2000) 'The Mantel-Pearson paradox: statistical considerations and ecological implications', *Journal of Agricultural, Biological and Environmental Statistics*, 5, pp. 131–150.

[Dwass \(1957\)](#)

Dwass, M. (1957) 'Modified randomization tests for nonparametric hypotheses', *Annals of Mathematical Statistics*, 28, pp. 181–187.

[Edgington \(1995\)](#)

Edgington, E.S. (1995) *Randomization tests, 3rd edition*. New York: Marcel Dekker.

[Ellingsen & Gray \(2002\)](#)

Ellingsen, K.E. and Gray, J.S. (2002) 'Spatial patterns of benthic diversity: is there a latitudinal gradient along the Norwegian continental shelf?', *Journal of Animal Ecology*, 71, pp. 373–389.

[Excoffier, Smouse & Quattro \(1992\)](#)

Excoffier, L., Smouse, P.E. and Quattro, J.M. (1992) 'Analysis of molecular variance inferred from metric distances among DNA haplotypes: application to human mitochondrial DNA restriction data', *Genetics*, 131, pp. 479–491.

[Faith, Humphrey & Dostine \(1991\)](#)

Faith, D.P., Humphrey, C.L. and Dostine, P.L. (1991) 'Statistical power and BACI designs in biological monitoring: comparative evaluation of measures of community dissimilarity based on benthic macroinvertebrate communities in Rockhole Mine Creek, Northern Territory, Australia', *Australian Journal of Marine and Freshwater Research*, 42, pp. 589–602.

[Faith, Minchin & Belbin \(1987\)](#)

Faith, D.P., Minchin, P.R. and Belbin, L. (1987) 'Compositional dissimilarity as a robust measure of ecological distance', *Vegetatio*, 69, pp. 57–68.

[Fisher \(1924\)](#)

Fisher, R.A. (1924) 'On a distribution yielding the error functions of several well-known statistics', in *Proceedings of the international congress of mathematics*. Toronto 2, pp. 805–813.

[Fisher \(1935\)](#)

Fisher, R.A. (1935) *Design of experiments*. Edinburgh: Oliver & Boyd.

[Fisher \(1936\)](#)

Fisher, R.A. (1936) 'The use of multiple measurements in taxonomic problems', *Annals of Eugenics*, 7(Part II), pp. 179–188.

[Fletcher, Mackenzie & Villouta \(2005\)](#)

Fletcher, D., Mackenzie, D. and Villouta, E. (2005) 'Modelling skewed data with many zeros: a simple approach combining ordinary and logistic regression', *Environmental and Ecological Statistics*, 12, pp. 45–54.

[Fletcher & Underwood \(2002\)](#)

Fletcher, D.J. and Underwood, A.J. (2002) 'How to cope with negative estimates of components of variance in ecological field studies', *Journal of Experimental Marine Biology and Ecology*, 273, pp. 89–95.

[Freedman & Lane \(1983\)](#)

Freedman, D. and Lane, D. (1983) 'A nonstochastic interpretation of reported significance levels', *Journal of Business and Economic Statistics*, 1, pp. 292–298.

[Gates \(1995\)](#)

Gates, C.E. (1995) 'What really is experimental error in block designs?', *The American Statistician*, 49, pp. 362–363.

[Gaylor & Hopper \(1969\)](#)

Gaylor, D.W. and Hopper, F.N. (1969) 'Estimating the degrees of freedom for linear combinations of mean squares by Satterthwaite's formula', *Technometrics: a journal of statistics for the physical, chemical, and engineering sciences*, 11, pp. 691–706.

[Geisser & Greenhouse \(1958\)](#)

Geisser, S. and Greenhouse, S.W. (1958) 'An extension of Box's results on the use of the F distribution in multivariate analysis', *Annals of Mathematical Statistics*, 29, pp. 885–891.

[Gittins \(1985\)](#)

Gittins, R. (1985) *Canonical analysis: a review with applications in ecology*. Berlin: Springer-Verlag.

[Glasby \(1997\)](#)

Glasby, T.M. (1997) 'Analysing data from post-impact studies using asymmetrical analyses of variance: a case study of epibiota on marinas', *Australian Journal of Ecology*, 22, pp. 448–459.

[Glasby \(1999\)](#)

Glasby, T.M. (1999) 'Interactive effects of shading and proximity to the seafloor on the development of subtidal epibiotic assemblages', *Marine Ecology Progress Series*, 190, pp. 113–124.

[Godinez-Dominguez & Freire \(2003\)](#)

Godinez-Dominguez, E. and Freire, J. (2003) 'Information-theoretic approach for selection of spatial and temporal models of community organisation', *Marine Ecology Progress Series*, 253, pp. 17–24.

[Gonzalez & Manly \(1998\)](#)

Gonzalez, L. and Manly, B.F.J. (1998) 'Analysis of variance by randomization with small data sets', *Environmetrics (London, Ont.)*, 9, pp. 53–65.

[Good \(1982\)](#)

Good, I.J. (1982) 'An index of separateness of clusters and a permutation test for its significance', *Journal of Statistical Computation and Simulation*, 15, pp. 261–275.

[Goodsell & Connell \(2002\)](#)

Goodsell, P.J. and Connell, S.D. (2002) 'Can habitat loss be treated independently of habitat configuration? Implications for rare and common taxa in fragmented landscapes', *Marine Ecology Progress Series*, 239, pp. 37–44.

[Gower \(1966\)](#)

Gower, J.C. (1966) 'Some distance properties of latent root and vector methods used in multivariate analysis', *Biometrika*, 53, pp. 325–338.

[Gower \(1974\)](#)

Gower, J.C. (1974) 'Algorithm AS 78: The mediancentre', *Applied Statistics*, 23, pp. 466–470.

[Gower \(1982\)](#)

Gower, J.C. (1982) 'Euclidean distance geometry', *Mathematical Scientist*, 7, pp. 1–14.

Gower (1987)

Gower, J.C. (1987) 'Introduction to ordination techniques', in P. Legendre and L. Legendre (eds) *Developments in numerical ecology*. Vol. G14, Springer-Verlag, Berlin: NATO ASI Series, pp. 3–64.

Gower & Hand (1996)

Gower, J.C. and Hand, D.J. (1996) *Biplots*. London: Chapman & Hall.

Gower & Krzanowski (1999)

Gower, J.C. and Krzanowski, W.J. (1999) 'Analysis of distance for structured multivariate data and extensions to multivariate analysis of variance', *Applied Statistics*, 48, pp. 505–519.

Gower & Legendre (1986)

Gower, J.C. and Legendre, P. (1986) 'Metric and Euclidean properties of dissimilarity coefficients', *Journal of Classification*, 3, pp. 5–48.

Gray, Clarke, Warwick et al. (1990)

Gray, J.S., Clarke, K.R., Warwick, R.M. and Hobbs, G. (1990) 'Detection of initial effects of pollution on marine benthos: an example from the Ekofisk and Eldfisk oilfields, North Sea', *Marine Ecology Progress Series*, 66, pp. 285–299.

Green & Oldman (1999)

Green, M.O. and Oldman, J.W. (1999) 'Deposition of flood-borne sediment in Okura estuary. ARC', Report No. ARC90242/2. National Institute of Water and Atmospheric Research, Hamilton, New Zealand [Preprint].

Green (1979)

Green, R.H. (1979) *Sampling design and statistical methods for environmental biologists*. New York: John Wiley & Sons.

Green (1993)

Green, R.H. (1993) 'Application of repeated-measures designs in environmental-impact and monitoring studies', *Australian Journal of Ecology*, 18, pp. 81–98.

Gurevitch & Chester (1986)

Gurevitch, J. and Chester, S.T. (1986) 'Analysis of repeated measures experiments', *Ecology*, 67, pp. 251-255.

[Haldane \(1948\)](#)

Haldane, J.B.S. (1948) 'Note on the median of a multivariate distribution', *Biometrika*, 35, pp. 414-415.

[Hartley \(1967\)](#)

Hartley, H.O. (1967) 'Expectations, variances and covariances of ANOVA mean squares by `synthesis'', *Biometrics. Journal of the International Biometric Society*, 23, pp. 105-114.

[Hartley & Searle \(1969\)](#)

Hartley, H.O. and Searle, S.R. (1969) 'On interaction variance components in mixed models', *Biometrics. Journal of the International Biometric Society*, 25, pp. 573-576.

[Hepner, Homewood & Taylor \(2002\)](#)

Hepner, I.J., Homewood, J. and Taylor, A.J. (2002) 'Methadone disrupts performance on the working memory version of the Morris water task', *Physiology & Behavior*, 76, pp. 41-49.

[Hines \(1996\)](#)

Hines, W.G.S. (1996) 'Pragmatics of pooling in ANOVA tables', *The American Statistician*, 50, pp. 127-139.

[Hocking \(1973\)](#)

Hocking, R.R. (1973) 'A discussion of the two-way mixed model', *The American Statistician*, 27, pp. 148-152.

[Hope \(1968\)](#)

Hope, A.C.A. (1968) 'A simplified Monte Carlo significance test procedure', *Journal of the Royal Statistical Society, Series B*, 30, pp. 582-598.

[Hoyle & Murphy \(2006\)](#)

Hoyle, F.C. and Murphy, D.V. (2006) 'Seasonal changes in microbial function and diversity associated with stubble retention versus burning', *Australian Journal of Soil Research*, 44, pp. 407-423.

[Hurlbert \(1971\)](#)

Hurlbert, S.H. (1971) 'The nonconcept of species diversity: a critique and alternative parameters', *Ecology*, 52, pp. 577-586.

[Hurlbert \(1984\)](#)

Hurlbert, S.H. (1984) 'Pseudoreplication and the design of ecological field experiments', *Ecological Monographs*, 54, pp. 187-211.

[Hurvich & Tsai \(1989\)](#)

Hurvich, C.M. and Tsai, C.-L. (1989) 'Regression and time-series model selection in small samples', *Biometrika*, 76, pp. 297-307.

[Huyhn & Mandeville \(1979\)](#)

Huyhn, H. and Mandeville, G.K. (1979) 'Validity conditions in repeated measures design', *Psychological Bulletin*, 86, pp. 964-973.

[Huynh & Feldt \(1970\)](#)

Huynh, H. and Feldt, L.S. (1970) 'Conditions under which mean square ratios in repeated measurements designs have exact F-distributions', *Journal of the American Statistical Association*, 65, pp. 1582-1589.

[Huynh & Feldt \(1976\)](#)

Huynh, H. and Feldt, L.S. (1976) 'Estimation of the Box correction for degrees of freedom from sample data in randomized and split-plot designs', *Journal of Educational Statistics*, 1, pp. 69-82.

[Janky \(2000\)](#)

Janky, D.G. (2000) 'Sometimes pooling for analysis of variance hypothesis tests: a review and study of a split-plot model', *The American Statistician*, 54, pp. 269-279.

[Johnson & Field \(1993\)](#)

Johnson, C.R. and Field, C.A. (1993) 'Using fixed-effects model multivariate analysis of variance in marine biology and ecology', *Oceanography and Marine Biology, Annual Review*, 31, pp. 177-221.

[Johnson & Wichern \(1992\)](#)

Johnson, R.A. and Wichern, D.W. (1992) *Applied multivariate statistical analysis, 3rd edition*. Englewood Cliffs, New Jersey: Prentice-Hall.

[Kempthorne \(1952\)](#)

Kempthorne, O. (1952) *The design and analysis of experiments*. New York: John Wiley & Sons.

Kempthorne (1966)

Kempthorne, O. (1966) 'Some aspects of experimental inference', *Journal of the American Statistical Association*, 61, pp. 11-34.

Kempthorne & Doerfler (1969)

Kempthorne, O. and Doerfler, T.E. (1969) 'The behaviour of some significance tests under experimental randomization', *Biometrika*, 56, pp. 231-248.

Kenkel & Orloci (1986)

Kenkel, N.C. and Orloci, L. (1986) 'Applying metric and nonmetric multidimensional scaling to some ecological studies: some new results', *Ecology*, 67, pp. 919-928.

Kennedy & Cade (1996)

Kennedy, P.E. and Cade, B.S. (1996) 'Randomization tests for multiple regression', *Communications in Statistics - Simulation and Computation*, 25, pp. 923-936.

Kiflawi & Spencer (2004)

Kiflawi, M. and Spencer, M. (2004) 'Confidence intervals and hypothesis testing for beta diversity', *Ecology*, 85, pp. 2895-2900.

Kruskal (1964)

Kruskal, J.B. (1964) 'Multidimensional scaling by optimizing a goodness of fit to a nonmetric hypothesis', *Psychometrika*, 29, pp. 1-28.

Kruskal (1965)

Kruskal, J.B. (1965) 'Analysis of factorial experiments by estimating monotone transformations of the data', *Journal of the Royal Statistical Society, Series B*, 27, pp. 251-263.

Kruskal & Wish (1978)

Kruskal, J.B. and Wish, M. (1978) *Multidimensional scaling*. Beverly Hills: Sage Publications.

Krzanowski (1993)

Krzanowski, W.J. (1993) 'Permutational tests for correlation matrices', *Statistics and Computing*, 3, pp. 37-44.

[Lachenbruch & Mickey \(1968\)](#)

Lachenbruch, P.A. and Mickey, M.R. (1968) 'Estimation of error rates in discriminant analysis', *Technometrics: a journal of statistics for the physical, chemical, and engineering sciences*, 10, pp. 1-11.

[Legendre \(2000\)](#)

Legendre, P. (2000) 'Comparison of permutation methods for the partial correlation and partial Mantel tests', *Journal of Statistical Computation and Simulation*, 67, pp. 37-73.

[Legendre & Anderson \(1999\)](#)

Legendre, P. and Anderson, M.J. (1999) 'Distance-based redundancy analysis: testing multispecies responses in multifactorial ecological experiments', *Ecological Monographs*, 69, pp. 1-24.

[Legendre, Borcard & Peres-Neto \(2005\)](#)

Legendre, P., Borcard, D. and Peres-Neto, P.R. (2005) 'Analyzing beta diversity: partitioning the spatial variation of community composition data', *Ecological Monographs*, 75, pp. 435-450.

[Legendre & Gallagher \(2001\)](#)

Legendre, P. and Gallagher, E.D. (2001) 'Ecologically meaningful transformations for ordination of species data', *Oecologia*, 129, pp. 271-280.

[Legendre & Legendre \(1998\)](#)

Legendre, P. and Legendre, L. (1998) *Numerical ecology, 2nd English edition*. Amsterdam: Elsevier.

[Levene \(1960\)](#)

Levene, H. (1960) 'Robust tests for equality of variances', in S.G. Ghurye et al. (eds) *Olkin I*. Stanford, California: Contributions to probability and statistics. Stanford University Press, pp. 278-292.

[Lingoes \(1971\)](#)

Lingoes, J.C. (1971) 'Some boundary conditions for a monotone analysis of symmetric matrices', *Psychometrika*, 36, pp. 195-203.

[Lubischew \(1962\)](#)

Lubischew, A.A. (1962) 'On the use of discriminant functions in taxonomy', *Biometrics. Journal of the International Biometric Society*, 18, pp. 455-477.

[Mac Nally & Timewell \(2005\)](#)

Mac Nally, R. and Timewell, C.A.R. (2005) 'Resource availability controls bird-assemblage composition through interspecific aggression', *The Auk*, 122, pp. 1097–1111.

[Magurran \(2004\)](#)

Magurran, A.E. (2004) *Measuring biological diversity*. Oxford: Blackwell Publishing.

[Makarencov & Legendre \(2002\)](#)

Makarencov, V. and Legendre, P. (2002) 'Nonlinear redundancy analysis and canonical correspondence analysis based on polynomial regression', *Ecology*, 83, pp. 1146–1161.

[Manly \(1994\)](#)

Manly, B.F.J., M. (1994) *Multivariate statistical methods: a primer, 2nd edition*. Boca Raton, Florida: Chapman and Hall.

[Manly \(1997\)](#)

Manly, B.F.J. (1997) *Randomization, bootstrap and Monte Carlo methods in biology, 2nd edition*. London: Chapman & Hall.

[Manly \(2006\)](#)

Manly, B.F.J. (2006) *Randomization, bootstrap and Monte Carlo methods in biology, 3rd edition*. London: Chapman & Hall.

[Manly \(1994\)](#)

Manly, B.F.J. (1994) *Multivariate statistical methods: a primer, 2nd edition*. Boca Raton, Florida: Chapman and Hall.

[Mantel \(1967\)](#)

Mantel, N. (1967) 'The detection of disease clustering and a generalized regression approach', *Cancer Research*, 27, pp. 209–220.

[Mardia \(1971\)](#)

Mardia, K.V. (1971) 'The effect of non-normality on some multivariate tests and robustness to nonnormality in the linear model', *Biometrika*, 58, pp. 105–21.

[Mardia, Kent & Bibby \(1979\)](#)

Mardia, K.V., Kent, J.T. and Bibby, J.M. (1979) *Multivariate analysis*. London: Academic Press.

[Mauchley \(1940\)](#)

Mauchley, J.W. (1940) 'Significance test for sphericity of a normal n-variate distribution', *Annals of Mathematical Statistics*, 11, pp. 204–209.

[McArdle \(1988\)](#)

McArdle, B.H. (1988) 'The structural relationship - regression in biology', *Canadian Journal of Zoology*, 66, pp. 2329–2339.

[McArdle \(1990\)](#)

McArdle, B.H. (1990) 'Detecting and displaying impacts of biological monitoring: spatial problems and partial solutions', *Proceedings of Invited Papers, XVth International Biometrics Conference, IBC, Budapest*, pp. 249–255.

[McArdle \(1994\)](#)

McArdle, B.H. (1994) 'BACI for community ecologists: permutation tests for interaction terms in multivariate analysis of variance on dissimilarity matrices', *Invited paper presented at the 4th Conference of The International Environmetrics Society (TIES), Burlington, Ontario, Canada* [Preprint].

[McArdle \(2003\)](#)

McArdle, B.H. (2003) 'Lines, models, and errors: regression in the field', *Limnology and Oceanography*, 48, pp. 1363–1366.

[McArdle & Anderson \(2001\)](#)

McArdle, B.H. and Anderson, M.J. (2001) 'Fitting multivariate models to community data: a comment on distance-based redundancy analysis', *Ecology*, 82, pp. 290–297.

[McArdle, Gaston & Lawton \(1990\)](#)

McArdle, B.H., Gaston, K.J. and Lawton, J.H. (1990) 'Variation in the size of animal populations: patterns, problems and artefacts', *Journal of Animal Ecology*, 59, pp. 439–454.

[McArdle & Anderson \(2004\)](#)

McArdle, B.H. and Anderson, M.J. (2004) 'Variance heterogeneity, transformations and models of species abundance: a cautionary tale', *Canadian Journal of Fisheries and Aquatic Sciences*, 61, pp. 1294–1302.

McLean, Sanders & Stroup (1991)

McLean, R.A., Sanders, W.L. and Stroup, W.W. (1991) 'A unified approach to mixed linear models', *The American Statistician*, 45, pp. 54-64.

Mead (1988)

Mead, R. (1988) *The design of experiments: statistical principles for practical application*. Cambridge: Cambridge University Press.

Mielke & Berry (2001)

Mielke, P.W. and Berry, K.J. (2001) *Permutation methods: a distance function approach*. New York: Springer-Verlag.

Millar, Anderson & Zunun (2005)

Millar, R.B., Anderson, M.J. and Zunun, G. (2005) 'Fitting nonlinear environmental gradients to community data: a general distance-based approach', *Ecology*, 86, pp. 2245-2251.

Minchin (1987)

Minchin, P.R. (1987) 'An evaluation of the relative robustness of techniques for ecological ordination', *Vegetatio*, 69, pp. 89-107.

Neter, Kutner, Nachtsheim et al. (1996)

Neter, J., Kutner, M.H., Nachtsheim, C.J. and Wasserman, W. (1996) *Applied linear statistical models, 4th edition*. Chicago, Illinois: Irwin.

Nishii (1984)

Nishii, R. (1984) 'Asymptotic properties of criteria for selection of variables in multiple regression', *Annals of Statistics*, 12, pp. 758-765.

O'Brien (1992)

O'Brien, P.C. (1992) 'Robust procedures for testing equality of covariance matrices', *Biometrics. Journal of the International Biometric Society*, 48, pp. 819-827.

Olson (1974)

Olson, C.L. (1974) 'Comparative robustness of six tests in multivariate analysis of variance', *Journal of the American Statistical Association*, 69, pp. 894-908.

[Olson \(1975\)](#)

Olson, C.L. (1975) 'A Monte Carlo investigation of the robustness of multivariate analysis of variance', *Psychological Bulletin*, 86, pp. 1350–1352.

[Olson \(1976\)](#)

Olson, C.L. (1976) 'On choosing a test statistic in multivariate analysis of variance', *Psychological Bulletin*, 83, pp. 579–586.

[Pearson & Blackstock \(1984\)](#)

Pearson, T.H. and Blackstock, J. (1984) *Garroch Head sledge dumping ground survey, final report*. Dunstaffnage Marine Research Laboratory (unpublished).

[Peres-Neto, Legendre, Dray et al. \(2006\)](#)

Peres-Neto, P.R., Legendre, P., Dray, S. and Borcard, D. (2006) 'Variation partitioning of species data matrices: estimation and comparison of fractions', *Ecology*, 87, pp. 2614–2625.

[Pertoldi, Garcia-Perea, Godoy et al. \(2006\)](#)

Pertoldi, C., Garcia-Perea, R., Godoy, J.A., Delibes, M. and Loeschcke, V. (2006) 'Morphological consequences of range fragmentation and population decline on the endangered Iberian lynx (*Lynx pardinus*)', *Journal of Zoology*, 268, pp. 73–86.

[Pesarin \(2001\)](#)

Pesarin, F. (2001) *Multivariate permutation tests with applications in biostatistics*. New York: John Wiley & Sons.

[Pillar & Orloci \(1996\)](#)

Pillar, V.D.P. and Orloci, L. (1996) 'On randomization testing in vegetation science: multifactor comparisons of releve groups', *Journal of Vegetation Science*, 7, pp. 585–592.

[Pitman \(1937a\)](#)

Pitman, E.J.G. (1937a) 'Significance tests which may be applied to samples from any populations', *Journal of the Royal Statistical Society, Series B*, 4, pp. 119–130.

[Pitman \(1937b\)](#)

Pitman, E.J.G. (1937b) 'Significance tests which may be applied to samples from any populations. II. The correlation coefficient test', *Journal of the Royal Statistical Society, Series B*, 4, pp. 225–232.

[Pitman \(1937c\)](#)

Pitman, E.J.G. (1937c) 'Significance tests which may be applied to samples from any populations. III. The analysis of variance test', *Journal of the Royal Statistical Society, Series B*, 4, pp. 322–335.

[Popper \(1959\)](#)

Popper, K.R. (1959) *The logic of scientific discovery*. London: Hutchinson.

[Popper \(1963\)](#)

Popper, K.R. (1963) *Conjectures and refutations: the growth of scientific knowledge*. London: Routledge and Kegan Paul.

[Prober, Thiele & Hunt \(2007\)](#)

Prober, S.M., Thiele, K.R. and Hunt, I.D. (2007) 'Fire frequency regulates tussock grass composition, structure and resilience in endangered temperate woodlands', *Austral Ecology*, 32, pp. 808–824.

[Quinn & Keough \(2002\)](#)

Quinn, G.P. and Keough, M.J. (2002) *Experimental design and data analysis for biologists*. Cambridge: Cambridge University Press.

[Rao \(1995\)](#)

Rao, C.R. (1995) 'A review of canonical coordinates and an alternative to correspondence analysis using Hellinger distance', *Questiio*, 19, pp. 23–63.

[Rao \(1968\)](#)

Rao, J.N.K. (1968) 'On expectations, variances, and covariances of ANOVA mean squares by `synthesis'', *Biometrics. Journal of the International Biometric Society*, 24, pp. 963–978.

[Raufaste & Rousset \(2001\)](#)

Raufaste, N. and Rousset, F. (2001) 'Are partial Mantel tests adequate?', 55, pp. 1703–1705.

[Rencher \(1988\)](#)

Rencher, A.C. (1988) 'On the use of correlations to interpret canonical functions', *Biometrika*, 75, pp. 363–365.

[Rencher \(1995\)](#)

Rencher, A.C. (1995) *Methods of multivariate analysis*. New York: John Wiley & Sons.

[Rencher \(1998\)](#)

Rencher, A.C. (1998) *Multivariate statistical inference and applications*. New York: John Wiley & Sons.

[Rousset \(2002\)](#)

Rousset, F. (2002) 'Partial mantel tests: reply to castellano and balletto', 56, pp. 1874–1875.

[Sakamoto, Ishiguro & Kitigawa \(1986\)](#)

Sakamoto, Y., Ishiguro, M. and Kitigawa, G. (1986) *Akaike information criterion statistics*. Tokyo: KTK Scientific Publishers.

[SAS Institute \(1999\)](#)

SAS Institute (1999) *SAS/STAT® user's guide, version 8*. Cary, North Carolina: SAS Institute.

[Satterthwaite \(1946\)](#)

Satterthwaite, F.E. (1946) 'An approximate distribution of estimates of variance components', *Biometrics Bulletin*, 2, pp. 110–114.

[Scheffé \(1959\)](#)

Scheffé, H. (1959) *The analysis of variance*. New York: John Wiley & Sons.

[Schwarz \(1978\)](#)

Schwarz, G. (1978) 'Estimating the dimension of a model', *Annals of Statistics*, 6, pp. 461–464.

[Searle \(1971\)](#)

Searle, S.R. (1971) *Linear models*. New York: John Wiley & Sons.

[Searle \(1987\)](#)

Searle, S.R. (1987) *Linear models for unbalanced data*. New York: John Wiley & Sons.

[Searle, Casella & McCulloch \(1992\)](#)

Searle, S.R., Casella, G. and McCulloch, C.E. (1992) *Variance components*. New York: John Wiley & Sons.

[Seber \(1982\)](#)

Seber, G.A.F. (1982) *The estimation of animal abundance and related parameters*, 2nd edition. London: Charles Griffin.

[Seber \(1984\)](#)

Seber, G.A.F. (1984) *Multivariate observations*. New York: John Wiley & Sons.

[Seber \(2008\)](#)

Seber, G.A.F. (2008) *A matrix handbook for statisticians*. Hoboken, New Jersey: John Wiley & Sons.

[Seber & Lee \(2003\)](#)

Seber, G.A.F. and Lee, A.J. (2003) *Linear regression analysis*, 2nd edition. Hoboken, New Jersey: John Wiley & Sons.

[Shears & Babcock \(2002\)](#)

Shears, N.T. and Babcock, R.C. (2002) 'Marine reserves demonstrate top-down control of community structure on temperate reefs', *Oecologia*, 132, pp. 131–142.

[Shears & Babcock \(2003\)](#)

Shears, N.T. and Babcock, R.C. (2003) 'Continuing trophic cascade effects after 25 years of no-take marine reserve protection', *Marine Ecology Progress Series*, 246, pp. 1–16.

[Shepard \(1962\)](#)

Shepard, R.N. (1962) 'The analysis of proximities: multidimensional scaling with an unknown distance function Parts I and II', *Psychometrika*, 27, pp. 125–140, 219–246.

[Sibson \(1979\)](#)

Sibson, R. (1979) 'Studies in the robustness of multidimensional scaling: perturbational analysis of classical scaling', *Journal of the Royal Statistical Society, Series B*, 41, pp. 217–229.

[Smith \(1998\)](#)

Smith, E.P. (1998) 'Randomization methods and the analysis of multivariate ecological data', *Environmetrics (London, Ont.)*, 9, pp. 37–51.

[Smith, Pontasch & Cairns \(1990\)](#)

Smith, E.P., Pontasch, K.W. and Cairns, J. (1990) 'Community similarity and the analysis of multispecies environmental data: a unified statistical approach', *Water Research*, 24, pp. 507–514.

Smith, Simpson & Cairns (1996)

Smith, S.D.A., Simpson, R.D. and Cairns, S.C. (1996) 'The macrofaunal community of Ecklonia radiata holdfasts: description of the faunal assemblage and variation associated with differences in holdfast volume', *Australian Journal of Ecology*, 21, pp. 81-95.

Smouse, Long & Sokal (1986)

Smouse, P.E., Long, J.C. and Sokal, R.R. (1986) 'Multiple regression and correlation extensions of the Mantel test of matrix correspondence', *Systematic Zoology*, 35, pp. 627-632.

Snedecor (1946)

Snedecor, G.W. (1946) *Statistical methods, 4th edition*. Ames, Iowa: Iowa State College Press.

Snedecor & Cochran (1989)

Snedecor, G.W. and Cochran, W.G. (1989) *Statistical methods, 8th edition*. Ames, Iowa: Iowa State University Press.

Somerfield, Gee & Warwick (1994)

Somerfield, P.J., Gee, J.M. and Warwick, R.M. (1994) 'Soft sediment meiofaunal community structure in relation to a long-term heavy metal gradient in the Fal estuary system', *Marine Ecology Progress Series*, 105, pp. 79-88.

Student (1908)

Student (1908) 'The probable error of a mean', *Biometrika*, 6, pp. 1-25.

Sugiura (1978)

Sugiura, N. (1978) 'Further analysis of the data by Akaike's information criterion and the finite corrections', *Communications in Statistics - Theory and Methods A*, 7, pp. 13-26.

Taylor (1961)

Taylor, L.R. (1961) 'Aggregation, variance and the mean', *Nature*, 189, pp. 732-735.

ter Braak (1985)

ter Braak, C.J.F. (1985) 'Correspondence analysis of incidence and abundance data: properties in terms of a unimodal response model', *Biometrics. Journal of the International Biometric Society*, 41, pp. 859-873.

[ter Braak \(1986a\)](#)

ter Braak, C.J.F. (1986a) 'Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis', *Ecology*, 67, pp. 1167-1179.

[ter Braak \(1986b\)](#)

ter Braak, C.J.F. (1986b) 'The analysis of vegetation-environment relationships by canonical correspondence analysis', *Vegetatio*, 69, pp. 69-77.

[ter Braak \(1987\)](#)

ter Braak, C.J.F. (1987) 'Ordination', in ter B.C. & van T.O. Jongman RHG (ed.) *Data analysis in community and landscape ecology*. Wageningen, The Netherlands: Pudoc, pp. 91-173.

[ter Braak \(1990\)](#)

ter Braak, C.J.F. (1990) 'Interpreting canonical correlation analysis through biplots of structure correlations and weights', *Psychometrika*, 55, pp. 519-531.

[ter Braak \(1992\)](#)

ter Braak, C.J.F. (1992) 'Permutation versus bootstrap significance tests in multiple regression and ANOVA', in R.G. & S.W. Jockel K-H (ed.) *Bootstrapping and related techniques*. Berlin: Springer-Verlag, pp. 79-86.

[Terlizzi, Anderson, Fraschetti, S. et al. \(2007\)](#)

Terlizzi, A., Anderson, M.J., Fraschetti, S. and Benedetti-Cecchi, L. (2007) 'Scales of spatial variation in Mediterranean sessile assemblages at different depths', *Marine Ecology Progress Series*, 332, pp. 25-39.

[Terlizzi, Scuderi, Fraschetti et al. \(2005\)](#)

Terlizzi, A., Scuderi, D., Fraschetti, S. and Anderson, M.J. (2005) 'Quantifying effects of pollution on biodiversity: a case study of highly diverse molluscan assemblages in the Mediterranean', *Marine Biology*, 148, pp. 293-305.

[Thompson \(1962\)](#)

Thompson, W.A. (1962) 'The problem of negative estimates of variance components', *Annals of Mathematical Statistics*, 33, pp. 273-289.

[Thompson & Moore \(1963\)](#)

Thompson, W.A. and Moore, J.R. (1963) 'Non-negative estimates of variance components', *Technometrics: a journal of statistics for the physical, chemical, and engineering sciences*, 5, pp. 441–449.

[Torgerson \(1958\)](#)

Torgerson, W.S. (1958) *Theory and methods of scaling*. New York: John Wiley & Sons.

[Tukey \(1949\)](#)

Tukey, J.W. (1949) 'One degree of freedom for non-additivity', *Biometrics. Journal of the International Biometric Society*, 5, pp. 232–242.

[Underwood \(1981\)](#)

Underwood, A.J. (1981) 'Techniques of analysis of variance in experimental marine biology and ecology', *Oceanography and Marine Biology, Annual Review*, 19, pp. 513–605.

[Underwood \(1991\)](#)

Underwood, A.J. (1991) 'Beyond BACI: experimental designs for detecting human environmental impacts on temporal variations in natural populations', *Australian Journal of Marine and Freshwater Research*, 42, pp. 569–587.

[Underwood \(1992\)](#)

Underwood, A.J. (1992) 'Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world', *Journal of Experimental Marine Biology and Ecology*, 161, pp. 145–178.

[Underwood \(1994\)](#)

Underwood, A.J. (1994) 'On Beyond BACI: sampling designs that might reliably detect environmental disturbances', *Ecological Applications*, 4, pp. 3–15.

[Underwood \(1997\)](#)

Underwood, A.J. (1997) *Experiments in ecology: their logical design and interpretation using analysis of variance*. Cambridge: Cambridge University Press.

[Underwood & Chapman \(1998\)](#)

Underwood, A.J. and Chapman, M.G. (1998) 'A method for analysing spatial scales of variation in composition of assemblages', *Oecologia*, 117, pp. 570–578.

[Underwood, Chapman & Connell \(2000\)](#)

Underwood, A.J., Chapman, M.G. and Connell, S.D. (2000) 'Observations in ecology: you can't make progress on processes without understanding the patterns', *Journal of Experimental Marine Biology and Ecology*, 250, pp. 97–115.

[Underwood & Petraitis \(1993\)](#)

Underwood, A.J. and Petraitis, P.S. (1993) 'Structure of intertidal assemblages in different locations: how can local processes be compared?', in R.E. Ricklefs and D. Schluter (eds) *Species diversity in ecological communities: historical and geographical perspectives*. Chicago: University of Chicago Press, pp. 38–51.

[van den Brink & ter Braak \(1999\)](#)

van den Brink, P. and ter Braak, C. (1999) 'Principal response curves: analysis of time-dependent multivariate responses of biological community to stress', *Environmental Toxicology and Chemistry*, 18, pp. 138–148.

[van der Aart & Smeek-Enserink \(1975\)](#)

van der Aart, P.J. and Smeek-Enserink, N. (1975) 'Correlations between distributions of hunting spiders (Lycosidae, Ctenidae) and environmental characteristics in a dune area', *Netherlands Journal of Zoology*, 25, pp. 1–45.

[van Valen \(1978\)](#)

van Valen, L. (1978) 'The statistics of variation', *Evolutionary Theory*, 4, pp. 33–43, 202.

[Vellend \(2001\)](#)

Vellend, M. (2001) 'Do commonly used indices of β -diversity measure species turnover?', *Journal of Vegetation Science*, 12, pp. 545–552.

[Verdonschot & ter Braak \(1994\)](#)

Verdonschot, P.F.M. and ter Braak, C.J.F. (1994) 'An experimental manipulation of oligochaete communities in mesocosms treated with chlorpyrifos or nutrient additions: multivariate analyses with Monte Carlo permutation tests', *Hydrobiologia*, 278, pp. 251–266.

[Warton & Hudson \(2004\)](#)

Warton, D.I. and Hudson, H.M. (2004) 'A MANOVA statistic is just as powerful as distance-based statistics, for multivariate abundances', *Ecology*, 85, pp. 858–874.

[Warton & Weber \(2002\)](#)

Warton, D.I. and Weber, N.C. (2002) 'Common slope tests for bivariate errors-in-variables models', *Biometrical Journal*, 44, pp. 161–174.

[Warton, Wright, Falster et al. \(2006\)](#)

Warton, D.I., Wright, I.J., Falster, D.S. and Westoby, M. et al. (2006) 'Bivariate line-fitting methods for allometry', *Biological Reviews*, 81, pp. 259–291.

[Warwick & Clarke \(1993\)](#)

Warwick, R.M. and Clarke, K.R. (1993) 'Increased variability as a symptom of stress in marine communities', *Journal of Experimental Marine Biology and Ecology*, 172, pp. 215–226.

[Warwick & Clarke \(1995\)](#)

Warwick, R.M. and Clarke, K.R. (1995) 'New `biodiversity' measures reveal a decrease in taxonomic distinctness with increasing stress', *Marine Ecology Progress Series*, 129, pp. 301–305.

[Warwick, Clarke & Gee \(1990\)](#)

Warwick, R.M., Clarke, K.R. and Gee, J.M. (1990) 'The effect of disturbance by soldier crab *Mictyris platycheles* H. Milne Edwards on meiobenthic community structure', *Journal of Experimental Marine Biology and Ecology*, 135, pp. 19–33.

[Warwick, Clarke & Suharsono \(1990\)](#)

Warwick, R.M., Clarke, K.R., and Suharsono (1990) 'A statistical analysis of coral community responses to the 1982-83 El Niño in the Thousand Islands, Indonesia', *Coral reefs (Online)*, 8, pp. 171–179.

[Welsh, Cunningham, Donnelly et al. \(1996\)](#)

Welsh, A.H., Cunningham, R.B., Donnelly, C.F. and Lindenmayer D.B. (1996) 'Modelling the abundance of rare species: statistical models for counts with extra zeros', *Ecological Modeling*, 88, pp. 297–308.

[Wessel & Schork \(2006\)](#)

Wessel, J. and Schork, N.J. (2006) 'Generalized genomic distance-based regression methodology for multilocus association analysis', *American Journal of Human Genetics*, 79, pp. 792–806.

[Wheldon, Anderson & Johnson \(2007\)](#)

Wheldon, M.C., Anderson, M.J. and Johnson, B.W. (2007) 'Identifying treatment effects in multi-channel measurements in electroencephalographic studies: multivariate permutation tests and

multiple comparisons', *Australian & New Zealand Journal of Statistics*, 49, pp. 397–413.

[Whittaker \(1960\)](#)

Whittaker, R.H. (1960) 'Vegetation of the siskiyou mountains, oregon and california', *Ecological Monographs*, 22, pp. 1–44.

[Whittaker \(1972\)](#)

Whittaker, R.H. (1972) 'Evolution and measurement of species diversity', *Taxon*, 21, pp. 213–251.

[Wickens \(1995\)](#)

Wickens, T.D. (1995) *The geometry of multivariate statistics*. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

[Willis & Anderson \(2003\)](#)

Willis, T.J. and Anderson, M.J. (2003) 'Structure of cryptic reef fish assemblages: relationships with habitat characteristics and predator density', *Marine Ecology Progress Series*, 257, pp. 209–221.

[Willis & Denny \(2000\)](#)

Willis, T.J. and Denny, C.M. (2000) 'Effects of poor knights islands marine reserve on demersal fish populations', *Report to the Department of Conservation, Research Grant No*, 2519.

[Willis, Millar & Babcock \(2003\)](#)

Willis, T.J., Millar, R.B. and Babcock, R.C. (2003) 'Protection of exploited fish in temperate regions: high density and biomass of snapper *Pagrus auratus* (Sparidae) in northern New Zealand marine reserves', *Journal of Applied Ecology*, 40, pp. 214–227.

[Winer, Brown & Michels \(1991\)](#)

Winer, B.J., Brown, D.R. and Michels, K.M. (1991) *Statistical principles in experimental design*, 3rd edition. New York: McGraw-Hill.

[Winsberg & Ramsay \(1980\)](#)

Winsberg, S. and Ramsay, J.O. (1980) 'Monotonic transformations to additivity using splines', *Biometrika*, 67, pp. 669–674.

[Winsor & Clarke \(1940\)](#)

Winsor, C.P. and Clarke, G.L. (1940) 'A statistical study of variation in the catch of plankton nets', *Journal of Marine Research*, 3, pp. 1-34.

[Yee \(2006\)](#)

Yee, T.W. (2006) 'Constrained additive ordination', *Ecology*, 87, pp. 203-213.

[Zhang \(1992\)](#)

Zhang, P. (1992) 'On the distributional properties of model selection criteria', *Journal of the American Statistical Association*, 87, pp. 732-737.

[Zhu, Hastie & Walter \(2005\)](#)

Zhu, M., Hastie, T.J. and Walter, G. (2005) 'Constrained ordination analysis with flexible response functions', *Ecological Modelling*, 187, pp. 524-536.

A3 Index to mathematical notation and symbols

Matrices and vectors

A = matrix containing elements $a_{ij} = -\frac{1}{2} d_{ij}^2$

B = matrix of variables ($N \times s$) that are linear combinations of normalised **X** variables having maximum correlation with CAP axes

C = matrix of CAP axes ($N \times s$), standardised by the square root of their respective eigenvalues

D = matrix containing elements d_{ij} corresponding to distances or dissimilarities

G = Gower's centred matrix, consisting of elements $g_{ij} = a_{ij} - \bar{a}_{i.} - \bar{a}_{.j} + \bar{a}_{..}$

H = 'hat' matrix = $\mathbf{X}(\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'$, used as a projection matrix for regression models

I = identity matrix, with 1's along the diagonal and 0's elsewhere

Q = matrix of PCO axes, standardised by the square root of their respective eigenvalues

\mathbf{Q}^0 = matrix of PCO axes, orthonormalised to SSCP = **I** ('sphericised')

U = matrix whose columns contain the left singular vectors from a singular value decomposition (SVD) of a matrix (e.g., $\mathbf{X} = \mathbf{U}\mathbf{W}\mathbf{V}'$); if **X** is ($N \times q$) and $q < N$, then **U** is ($N \times q$)

V = matrix whose columns contain the right singular vectors from a singular value decomposition (SVD) of a matrix (e.g., $\mathbf{X} = \mathbf{U}\mathbf{W}\mathbf{V}'$); if **X** is ($N \times q$) and $q < N$, then **V** is ($q \times N$)

W = diagonal matrix of eigenvalues from a singular value decomposition (SVD) of a matrix (e.g., $\mathbf{X} = \mathbf{U}\mathbf{W}\mathbf{V}'$); if **X** is ($N \times q$) and $q < N$, then **W** is ($q \times q$)

X = matrix of predictor variables ($N \times q$) (often a set of environmental variables)

\mathbf{X}^0 = matrix of **X** variables, orthonormalised to SSCP = **I** ('sphericised')

Y = matrix of response variables ($N \times p$) (often a set of species variables)

\mathbf{Y}^0 = matrix of **Y** variables, orthonormalised to SSCP = **I** ('sphericised')

$\hat{\mathbf{Y}} = \mathbf{H}\mathbf{Y}$ = matrix of fitted values ($N \times p$)

\mathbf{y}_{ij} = vector of p response variables for the j th observation in the i th group

$\bar{\mathbf{y}}_i$ = the centroid vector of p response variables for group i

Z = matrix of dbRDA canonical axes ($N \times s$)

Letters

a, b, c , etc... = number of levels of factor A, B, C, etc... in an ANOVA experimental design

AIC = multivariate analogue to Akaike's 'An information criterion'

AIC_c = multivariate analogue to the small-sample-size corrected version of AIC

B_l = the l th variable in the space of normalised **X** variables that has maximum correlation with the l th coordinate axis (C_l) from a CAP analysis

BIC = multivariate analogue to Schwarz's 'Bayesian information criterion'

$C_{i,l}$ = the l th coordinate axis scores from a CAP analysis
 d_{ij} = distance or dissimilarity between sample i and sample j
 df = degrees of freedom
 F = pseudo- F statistic for testing hypotheses in PERMANOVA or DISTLM
 i = index used for samples (i.e., $i = 1, \dots, N$) or index used for groups ($i = 1, \dots, a$)
 j = second index used for samples (i.e., $j = 1, \dots, N$) **or** index used for replicates within a group ($j = 1, \dots, n$)
 k = index used for variables (i.e., $k = 1, \dots, p$ or else $k = 1, \dots, q$)
 l = index used for canonical axes or eigenvalues for either dbRDA **or** CAP (i.e., $l = 1, \dots, s$) **or** either the abbreviation for 'log-likelihood' or the 'length' of a vector (depending on context).
 m = number of PCO axes chosen as a subset for analysis by CAP
 MC = Monte Carlo
 MS = mean square
 N = total number of samples
 n = number of samples (replicates) within a group or cell in an experimental design
 P = P -value associated with the test of a null hypothesis
 p = number of multivariate response variables in matrix **Y**
 q = total number of predictor variables in matrix **X**
 r = Pearson correlation coefficient
 R = the ANOSIM R statistic (see [Clarke \(1993\)](#))
 R^2 = proportion of explained variation from a model
 s = number of canonical eigenvalues and associated canonical axes obtained from either a dbRDA **or** a CAP analysis
 SS = sum of squares
 $SSCP$ = sum of squares and cross products
 SVD = singular value decomposition
 t = pseudo- t statistic = $\sqrt{\text{pseudo-}F}$
 tr = 'trace' of a matrix = the sum of the diagonal elements
 X_k = the k th predictor variable
 Y_k = the k th response variable
 z_{ij} = distance to group centroid for the j th replicate within the i th group.

Greek symbols and matrices

α = significance level chosen for a test (usually $\alpha = 0.05$).
 Δ_l^2 = the l th eigenvalue from a CAP analysis, a squared canonical correlation
 Δ = diagonal matrix containing the square roots of the eigenvalues from a CAP analysis (a capital delta)
 γ_l^2 = the l th eigenvalue from a dbRDA analysis, a portion of the explained (regression) sum of squares from a dbRDA model.
 Γ = diagonal matrix containing the square roots of the eigenvalues from a dbRDA analysis (a capital gamma)
 λ_i = the i th eigenvalue from a PCO analysis
 Λ = diagonal matrix of eigenvalues from a PCO analysis (a capital lambda)
 ν = number of parameters in a particular model during model selection

ρ = Spearman rank correlation (ρ)

\sum = sum over the relevant index

A4 Index to data sets used in examples

Below is an index to the data sets used in examples, listed in order of appearance in the text. With each dataset are given the name and location of the data file, the original reference, a description of its use as an example in the manual and the page number where this can be found (italicised and in parentheses).

1. Ekofisk oil-field macrofauna ([ekma.pri](#) in Examples v6\Ekofisk), [Gray, Clarke, Warwick et al. \(1990\)](#) - demonstrate one-way PERMANOVA ([1.8](#)), model selection procedures, diagnostics and building models in DISTLM ([4.10](#)) and visualising models using dbRDA ([4.11](#)).
2. Victorian avifauna ([vic.pri](#) in Examples add-on\VictAvi), [Mac Nally & Timewell \(2005\)](#) - demonstrate Monte Carlo *P* values ([1.12](#)). Also used at the level of individual surveys ([vicsurv.pri](#)) to demonstrate a repeated measures design ([1.32](#)) and also PCO ([3.4](#)), negative eigenvalues ([3.5](#)), scree plots ([3.5](#)) and vector overlays ([3.6](#)).
3. Subtidal epibiota ([sub.pri](#) in Examples add-on\SubEpi), [Glasby \(1999\)](#) - demonstrate a two-way crossed design ([1.14](#)) and contrasts ([1.19](#)) in PERMANOVA.
4. Tasmanian meiofauna ([tas.pri](#) in Examples add-on\TasMei), [Warwick, Clarke & Gee \(1990\)](#) - demonstrate fixed *versus* random factors ([1.20](#)), components of variation ([1.21](#)), expected mean squares ([1.22](#)), constructing F from EMS ([1.23](#)), exchangeable units ([1.24](#)), inference space and power ([1.25](#)), and testing the design ([1.26](#)).
5. Holdfast invertebrates ([hold.pri](#), [holdenv.pri](#) and [Mollusca.agg](#) in Examples add-on\HoldNZ), [Anderson, Diebel, Blom et al. \(2005\)](#) - demonstrate a nested design ([1.27](#)), estimating components of variation ([1.28](#)), and pooling or excluding terms ([1.29](#)). Also used later to demonstrate analyses with covariates in PERMANOVA ([1.35](#)) and marginal and conditional tests with DISTLM ([4.6](#)).
6. Plankton net study ([plank.pri](#) in Examples add-on\Plankton), [Winsor & Clarke \(1940\)](#) - demonstrate designs that lack replication ([1.30](#)) and increased power as a result of blocking ([1.30](#)).
7. Woodstock plants ([wsk.pri](#) in Examples add-on\Woodstock), [Prober, Thiele & Hunt \(2007\)](#) - demonstrate a split-plot design ([1.31](#)).
8. Birds from Borneo ([born.pri](#) in Examples add-on\BorneoBirds), [Cleary, Genner, Boyle et al. \(2005\)](#) - demonstrate an unbalanced design ([1.34](#)).

9. New Zealand fish ([fishNZ.pri](#) in Examples add-on\FishNZ), [Anderson & Millar \(2004\)](#) – demonstrate analyses involving linear combinations of mean squares ([1.36](#)).
10. Mediterranean molluscs ([medmoll.pri](#) in Examples add-on\MedMoll), [Terlizzi, Scuderi, Fraschetti et al. \(2005\)](#) – demonstrate an asymmetrical design ([1.37](#)).
11. Bumpus' sparrows ([spar.pri](#) in Examples add-on\BumpSpar), [Bumpus \(1898\)](#) – demonstrate test of dispersion in Euclidean space ([2.3](#)).
12. Tikus Island corals ([tick.pri](#) in Examples v6\Corals), [Warwick, Clarke & Suharsono \(1990\)](#) – demonstrate test of dispersion for ecological data ([2.7](#)) and how choice of dissimilarity measure matters ([2.8](#)). Also used later to demonstrate how CAP tells you nothing about relative within-group dispersions ([5.9](#)).
13. Norwegian macrofauna ([norbio.pri](#) and [norenv.pri](#) in Examples add-on\NorMac), [Ellingsen & Gray \(2002\)](#) – demonstrate use of the test of dispersion to investigate beta diversity ([2.9](#)).
14. Okura macrofauna ([okura.pri](#), in Examples add-on\Okura), [Anderson, Ford, Feary et al. \(2004\)](#) – demonstrate tests of dispersion in nested designs ([2.11](#)). Also used to demonstrate PCO of distances among centroids ([3.8](#)) and PCO *versus* MDS when samples are split into groups ([3.9](#)).
15. Cryptic fish assemblages ([cryptic.pri](#) in Examples add-on\Cryptic), [Willis & Anderson \(2003\)](#) – demonstrate PERMDISP for a two-factor crossed design, in conjunction with PERMANOVA ([2.12](#)).
16. Clyde macrofauna and environmental data ([clma.pri](#) and [clev.pri](#), in Examples v6\Clydemac), [Pearson & Blackstock \(1984\)](#) – demonstrate PCO *versus* PCA for environmental data ([3.7](#)) and simple linear regression using DISTLM ([4.4](#)).
17. Thau lagoon bacteria ([thbac.pri](#) and [thevsp.pri](#) in Examples add-on\Thau), [Amanieu, Legendre, Troussellier et al. \(1989\)](#) – demonstrate analysing variables in sets using DISTLM ([4.14](#)).
18. Oribatid mites ([ormites.pri](#) and [orenvgeo.pri](#) in Examples add-on\OrbMit), [Borcard, Legendre & Drapeau \(1992\)](#) – demonstrate analysing categorical predictor variables using DISTLM ([4.15](#)).
19. Flea-beetles ([flea.pri](#) in Examples add-on\FleaBeet), [Lubischew \(1962\)](#) – demonstrate the rationale for CAP by comparing unconstrained vs constrained ordination ([5.2](#)).
20. Poor Knights Islands fish ([pkfish.pri](#) in Examples add-on\PKFish), [Willis & Denny \(2000\)](#) – demonstrate discriminant analysis based on Bray-Curtis using CAP ([5.4](#)).
21. Iris data ([iris.pri](#) in Examples add-on\Iris), [Anderson \(1935\)](#) – demonstrate classical discriminant analysis and MANOVA test statistics using CAP ([5.7](#)). Also used later to show

how the positions of new samples are added into a discriminant-type analysis, with prediction of group membership (5.10).

22. Fal estuary biota (**Fa.xls** in Examples v6\Fal; **falbio.pri** and **falenv.pri** in Examples add-on\FalEst), [Somerfield, Gee & Warwick \(1994\)](#) – demonstrate canonical correlation analysis with CAP based on the Bray-Curtis measure relating biota to a single environmental gradient (5.11).
23. Hunting spiders (**hspi.pri** and **hspienv.pri** in Examples add-on\Spiders), [van der Aart & Smeek-Enserink \(1975\)](#) – demonstrate a canonical correlation-type analysis using CAP on the basis of chi-squared distances (5.16).