An Annotated Bibliography of Similarity Indices in Ecology

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Papers are divided into three parts: Part 1 – Similarity Metrics: Approaches and Critiques; Part II –Detecting Change in Community Structure: Analytic and Statistical Approaches; Part III – Applications of Similarity Indices.

I. Similarity Metrics: Approaches and Critiques

Baroni-Urbani, C., and M.W. Buser. (1976) Similarity of binary data. *Syst. Zool.* 25:251-259.
The authors depart from convention by incorporating the mutual absence of species, not just their presence, between two samples in a calculation of their compositional or phylogenic similarity. Such "negative matches" are often excluded from similarity indices because their interpretation is thought to be too ambiguous. These authors argue that shared absences and the frequency of rare characters or species are crucial to characterizing similarity, because negative matches are critical parameters of the statistical distribution of characters/species abundances across all samples or individuals. They derive their arguments mathematically in a brief appendix.

Bloom, S.A. (1981) Similarity indices in community studies: potential pitfalls. *Marine Ecology* – Progress Series 5: 125-128.
This short note serves as a warning to ecologists who are interested in using similarity indices to compare community composition between sites because over- or under-estimation of many indices. The author suggests justifying the use of a chosen index for any study and recommends using Czekanowski's Quantitative Index (a.k.a. Sörenson) as the index that most accurately revealed similarity between samples. A couple of cautions about this paper, first, the author doesn't use data to compare each index, but instead uses response curves for each to see how and where each curve overlaps. Second, and possibly more important, the curves are normal distribution curves, but species abundances do not follow a normal distribution therefore, the author's comparisons may be bogus.

Bray, J.R., and J.T. Curtis. (1957) An ordination of the upland forest communities of southern Wisconsin. *Ecological Monographs* 27(4): 325-349.
This paper is always cited when authors use their index of similarity. It is doubtful that any author has actually read the paper; however, Bray and Curtis developed the index ultimately to perform an ordination analysis on plant community data gathered in S. Wisconsin to reveal forest community structure (another attempt at resolving Clements-Gleason debate). It is worth reading if just for the image of the hand-built three-dimensional ordination model.

Cao, Y., and D.P. Larsen. (2001) Rare species in multivariate analysis for bioassessment: some considerations. *Journal of the North American Benthological Society* 20(1): 144-153.
In keeping with their other papers, this investigation illustrates how sensitive similarity indices and multivariate comparisons are to sample size. The role of rare – or more aptly

rarely detected --species in changing the results of multivariate similarity analysis is considered in detail.

Cao, Y., D.P. Larsen, R.M. Hughes, P.L. Angermeier, and T.M. Patton. (2002) Sampling effort affects multivariate comparisons of streams assemblages. *Journal of the North American Benthological Society* 21(4): 701-714.
Cao et al use three data sets (1 of benthic invertebrates, 2 of fish) to document the high degree to which sampling effort changes the outcome of multivariate techniques --which rely on similarity indices to describe differences between communities. This is one of the first papers to investigate the behavior of both similarity metrics and their complicated modern incarnations, the ordination and clustering techniques. Ordinators beware: getting a stable, or reliable, description of community differences was not possible without intensive sampling.

Cao, Y., D.D. Williams, and D.P. Larsen. (2002) Comparison of ecological communities: the problem of sample representativeness. *Ecological Monographs* 72(1): 41-56.
Building on issues developed in other papers the same year, Cao et al. investigate the use of similarity indices to set minimum thresholds for sampling and enable accurate comparisons among communities. They argue for the use of "representative" samples in comparing species diversity and structure among different communities or sites. They devise a method of detecting adequate representation based on increasing sampling effort until "autosimilarity" is achieved, and argue each community will require different levels of sampling.

Chao, A., W-H Hwang, Y-C Chen, and C-Y Kuo. (2000) Estimating the number of shared species in two communities. *Statistica Sinica* 10: 227-246.
These authors attempt to improve estimates of community similarity by accounting for the number of undetected, but shared, species in a sample. They describe in detail the statistical acrobatics involved in estimating the degree to which a sample is incomplete and how to adjust a sample *ad hoc* for the probability it has missed any shared species. They suggest using the least-frequent of the shared species in empirical data to estimate the probability of undetected shared species remaining in the communities. However, because the model is developed from the sample data itself, it does not seem to me to be externally valid or a complete reference distribution to judge the adequacy of a sampling technique. The reference distribution (the model of detection probabilities) is principally based on, and therefore limited by, sampling effort, not necessarily on the biological behavior of the organisms involved. Time spent estimating how inadequate a sample is could better be spent in the field gathering more data and uncovering hard to detect species – or whether they were just overlooked.

Chao, A., R.L. Chazdon, R.K. Colwell, and T-J Shen. (2005) A new statistical approach for assessing similarity of species composition with incidence and abundance data. *Ecology Letters* 8: 148-159.
The authors refine the earlier approach of Cao et al (2000) to develop a correction factor for a particular class of similarity indices, the Jaccard and Sorensen indices. Again, the incidence and abundance of species in a given sample is used to estimate the number of

"missed" couples. This method derives corrections from the distribution of even less frequent matches than the earlier work, defining "rare" matches as those that occur only once or twice in a given pair of samples. Like diversity estimators, this method represents a quantitative fudge-factor that can not redress deficiencies in experimental design (sampling) or analysis.

Connor, E.F and D. Simberloff (1978) Species number and compositional similarity of the Galapagos flora and avifauna. Ecological Monographs 48: 219-248. Connor and Simberloff provide a comprehensive review of the experimental issues involved in drawing conclusions about species richness and compositional overlap in the Galapagos Islands. The section on similarity indices stands as one of the most accessible and ecologically motivated treatments of the subject and effectively instructs the reader on the statistical and conceptual limitations these indices have. Most importantly, it explicitly addresses the lack of null hypotheses in similarity comparisons, answering the question: What do we expect to find and why?

Faith, D.P., P.R. Minchin and L. Belbin. (1987) Compositional dissimilarity as a robust measure of ecological distance. *Vegetatio* 69: 57-68.
The authors report their results of testing the performance of different similarity indices in representing another metric, "ecological distance". Ecological distance is not defined biologically but as the multidimensional space that separates two samples, sites or communities. Species abundances are used to construct the multidimensional coordinates that define ecological distance. They find the Bray-Curtis (dis-)similarity metric to best approximate ecological distance, and as a result many researchers have taken up the index in their investigations, such as for the ANOSIM algorithm. Regardless of its ability to capture their abstract definition of ecological distance, Wolda's tests remind us that the index can be extremely biased under conditions of small sample size and low sample effort.

Grassle, J.F., and W. Smith. (1976) A similarity measure sensitive to the contribution of rare species and its use in investigation of variation in marine benthic communities. *Oecologica* 25:13-22.
Grassle and Smith attempt to rectify the bias and subjectivity in typical similarity indices by basing their comparisons on underlying biology and species pool available to communities. The derive a measure of expected species shared by formulating the probability that multiple sampling draws of a given size will eventually lead an average, or expected, number of shared species. Their measure is a generalization of Morisita's index.

Horn, H., (1966) Measurement of "overlap" in comparative ecological studies. *The American Naturalist* 100(914): 419-424.
Horn simplifies Morisita's index and uses it to quantify degree of niche overlap between species in a community. He and others attempts to use similarity as evidence that competitive relationships structure communities' species composition.

Huhta, V., (1979) Evaluation of different similarity indices as measures of succession in Arthropod communities of the forest floor after clear-cutting. *Oecologia* 41: 11-23.
Huhta compares the performance of 16 different similarity indices in capturing the successional change noticed by the author in beetle and spider communities after dramatic habitat alteration. Interestingly, one of the most often recommended indices, Morisita's "C", failed to reveal the alleged change in the animal communities. However, it is not clear if the results are artifacts of sampling or truly reflect a lack of change in community structure.

Izsak, J., (1999) Notes on asymmetrical similarity indices. Oikos 84(2): 343-345.
Izsak expands and refines Kunin's proposed index. A heavily jargon-laden statistical treatment that is not very accessible.

Krebs, Charles. 1999. " Similarity Coefficients and Cluster Analysis," pp. 375-393,in *Ecological Methodology*, 2nd ed. Menlo Park: Addison Wesley Longman, Inc.
Brief, accessible introduction to the most common types of similarity indices and the authors who have developed them. An excellent resource for clarifying possible uses and relevance of different indices.

Kunin, W.E. (1995) Towards an asymmetric index of community similarity. *Oikos* 73(3): 442-446.
Kunin takes a novel approach towards similarity indices and derives a probability metric that intentionally changes value according to the focal point (sample or plot) of observation. His metric is derived from the highly-esteemed Morisita index. Many probability based indices calculate similarity based on the likelihood of drawing two identical species or individuals simultaneously from either a) a hypothesized regional pool of species or b) a local pool represented by the two samples/communities being compared. Kunin derives a slightly different probability, that of drawing an identical species in a separate sampling event, from another, second sample. Kunin contends that this independent sampling model of shared species will more accurately detect and reflect nested subsets among communities, and therefore be useful in assessing the "invasibility" of neighboring plots. This metric has eluded common use in the literature.

Legendre, P. and L. Legendre. (1998) Numerical Ecology, 2nd ed. New York: Elsevier.
These two prominent statistical ecologists devote an entire chapter to defining ecological "resemblance" and the coefficients used to measure it. This is not a chapter for the statistically faint of heart, but is an essential resource for anyone who will spend a lot of time investigating community structure and composition.

Norris, K.C., (1999) Quantifying change through time in spider assemblages: sampling methods, indices and sources of error. *Journal of Insect Conservation* 3: 309-325.
Like Huhta's examination of spiders and beetles, Norris applies a multitude of indices to data she collected on spiders in an eastern deciduous forest and compares their performance. Like Huhta and Wolda, Norris finds that indices are very sensitive to sample size, sample effort and underlying diversity of the samples and communities

being compared. None are very well-behaved or reliable, but she has a few noteworthy recommendations and comments.

Phillippi, T.E., P.M. Dixon, and B.E. Taylor. (1998) Detecting trends in species composition. *Ecological Applications* 8(2): 300-308.
The authors of this paper use zooplankton and bird data to employ ways of testing community dissimilarity over time and between sites. The authors suggest that dissimilarity measures are the most appropriate for monitoring changes in species composition over time. They propose a way to define trends of change in species over time as 'progressive change'- the dissimilarity in species composition between two samples tends to increase over time. The authors next outline ways to test progressive change using Kendall's tau correlation, Spearman's rank correlation and a Mantel test. They use Bray-Curtis metric to calculate dissimilarity for both data sets and find no evidence of progressive change for the zooplankton data, but a trend is detected in the bird data. Make an argument for using permanent plots in monitoring designs to detect trends in community change, but don't address whether permanent plots are always biologically appropriate.

Plotkin, J.B., and H.C. Muller-Landau. (2002) Sampling the species composition of a landscape. *Ecology* 83(12): 3344-3356.
The authors put the reliability and accuracy of similarity indices in biological context. They aptly demonstrate how spatial aggregation and abundance distribution of species can dramatically affect indices of community composition, and how to consider these parameters in the formulation of community comparisons. This is an excellent resource for framing the use and misuse of similarity indices and for developing ecologically sound models of compositional overlap.

Potts, J.M. (1998) An alternative asymmetric index of community similarity. *Oikos* 82(2): 395-396.
Potts attempts to improve on the index proposed by Kunin (see above) by improving its "behavior" (i.e., tendency to give different results for the same data set). However, as she notes, her improvement fails to escape from a common problem among similarity metrics: their lack of independence from sample size and diversity.

Simberloff, D.S. and E.F. Connor. (1979) Q-mode and R-mode analyses of biogeographic distributions: null hypotheses based on random colonization. *Patil and Rosenzweig eds. Contemporary Quantitative Ecology and Related Ecometrics, pp123-138.* International Co-operative Publishing House, Fairland, Maryland.
Connor and Simberloff derive a similarity index based on the degree of deviation of the number of shared species at two given sites from that expected under a specified null hypothesis. Thus, the index is relative (or "probabilisitic") and provides a means of inference. The authors provide a simple, yet instructive example from the Galapagos Island avifauna that sheds light on both the statistical and biological issues involved in using similarity indices.

Smith, W. (1989) ANOVA-like similarity analysis using expected species shared. *Biometrics* 45: 873-881.

Smith derives a "similarity" index by measuring the expected number of species shared by two collections or samples. Expected species shared are derived from the probability of drawing shared species from a specified population model. The observed species shared between two samples are compared to that expected when drawing two samples from the same community; deviation from the expectation then provides evidence of variation, hence change. Smith proposes a method to decompose the variation in the deviation into its primary sources, thus revealing factors beyond random colonization that are responsible for structuring communities.

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Streever, W.J. and S.A. Bloom. (1993) The self-similarity curve: a new method of determining the sampling effort required to characterize communities. *Journal of Freshwater Ecology* 8(4): 401-403.

This short paper is one of the first that proposes a way to first find out how similar the samples gathered at a particular site are to each other. The goal of this method is to test for sufficient sampling. If the samples taken at a site are not very similar to each other greater sampling effort is suggested before testing for similarity between sites(also see Cao et al. (2002)).

Tamas, J., J. Podani, and P. Csontos. (2001) An extension of presence/absence coefficients to abundance data: a new look at absence. *Journal of Vegetation Science* 12: 401-410.

The authors develop a method for including and quantifying "absence" data in vegetation samples and how this affects similarity indices. They then explore the effect these revised measurements have on ordination and vegetation classification. The authors argue that their index allows for more methodological flexibility, without compromising rigor.

Wolda, H., (1981) Similarity indices, sample size, and diversity. *Oecologia* 50: 296-302.

Wolda presents and tests 22 similarity indices for effects of sample size and diversity on the robustness of each test. Simulates populations and takes random samples of different sizes from four different diversities of log normally distributed insect fauna. The author finds Morisita's index to be independent of sample size and diversity and makes recommendations for the use of many of the other indices tests. This paper is recommended for anyone interested in using similarity indices as a good starting point for choosing an index to use, and is the most often cited reference in contemporary use of similarity indices.

II. Detecting Changes in Community Composition: Analytic/Statistical Techniques

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

Anderson describes a statistical approach for assessing the statistical significance of differences in species assemblages among sites, not just describing the differences as most similarity indices do. The technique is very similar to the increasingly popular "ANOSIM" program employed by marine ecologists and develops a similar "F" statistic. A good review of statistical issues involved in the modeling and testing of the non-normal, multivariate data that comprise community data sets.

Clarke, K.R. (1993) Non-parametric multivariate analysis of changes in community structure. *Australian Journal of Ecology* 18: 117-143.
Building on the work of Smith et al (1990) and recommendations of Faith et al., Clarke develops a statistic, Clarke's R, that can be used to assess the significance of between to within-site variation in species abundances. Its conceptual goal is similar to the F statistic used in ANOVA, and hence has been coined "ANOSIM". ANOSIM employs the Bray-Curtis similarity measure, largely based on the recommendation of Faith et al (1987) it seems, but certainly other measures may prove useful.

Smith, E.P., K.W. Pontasch and J.Carns Jr. (1990) Community similarity and the analysis of multispecies environmental data: a unified statistical approach. *Wat. Res*. 24(4) 507-514.
This research represents one of the first attempts to derive an analytic approach to assessing similarity in communities, rather than the descriptive approaches embodied by similarity metrics. The interest in the research stems from the need to develop an alternative to the parametric technique MANOVA, which requires ecological data to meet assumptions they usually can not, even with transformation.

As a first step Smith et al's approach uses a similarity measure to summarize compositional differences in species abundances on two different levels (both within sites and between sites). Second the ratio of between- to within-site variation for these data is calculated. Finally, similarity measures are randomly re-assigned to different replicates and sites a number of times to generate different ratios of between- to within-site variation, and the resulting frequency distribution of possible values can be used to evaluate the relative probability of encountering the observed ratio. Thus, a statistical inference can be made on the likelihood of species abundance, and therefore, community structure, varying between sites. This research forms the groundwork for the ANOSIM statistical software developed later by marine ecologists Clarke and Warwick (see below).

Somerfield, P.J., K.R. Clarke and F. Olsgard. (2002) A comparison of the power of categorical and correlational tests applied to community ecology data from gradient studies. *Journal of Animal Ecology* 71: 581-593.
These authors are some of the few who have investigated the statistical power of the recent non-parametric multivariate techniques developed to objectively and quantitatively assess differences in ecological community composition – without resorting to the biased similarity metrics. In particular they compare the power of ANOSIM, a categorical test analogous to ANOVA, to RELATE, a correlative analogue to linear regression. The authors find that both correlative techniques are more powerful than either categorical techniques (ANOVA or ANOSIM) in their ability to detect a gradient of change in community composition. Excellent review of the methods and approaches involved in analyzing multi-species assemblages as response variables.

Solow, A.R., (1993) A simple test for change in community structure. *Journal of Animal Ecology* 62: 191-193.

Solow demonstrates how to use resampling and randomization techniques to assess the significance of purported changes in community structure.

Warton, D.I., and H.M. Hudson. (2004) A MANOVA statistic is just as powerful as distance-based statistics, for multivariate abundances. *Ecology* 85(3): 858-874.

Warton and Hudson investigate conditions under which parametric treatments of species assemblages (like MANOVA) are as powerful as the newer, non-parametric approaches like ANOSIM and Anderson's (2001, see above). The authors' endorsement of MANOVA should be taken with a grain of salt; they themselves provide many cases wherein newer techniques are more effective and powerful.

III. Some Applications of Similarity Indices

Azovsky, A.I. (1996) The effect of scale in congener coexistence: can molluscs and polychaetes reconcile beetles to ciliates? *Oikos* 77(1): 117-126.

Authors utilize similarity indices to test species coexistence theory. Read to find out how indices were being used in (somewhat) current literature. One of very few that use similarity indices to test any ecological mechanistic theories.

Cleary, D.F.R., A.O. Mooers, K.A.O. Eichhorn, J. van Tol, R. de Jong, and S.B.J. Menken. (2004) Diversity and community compositon of butterflies and odonates inan ENSO-induced fire affected habitat mosaic: a case study from East Kalimantan, Indonesia. *Oikos* 105(2): 426-448.

This is an application paper in which the authors compare the community composition of two separate taxa in burned and unburned landscapes. The authors use a similarity matrix as part of the program PRIMER and then used the matrix for MDS ordination as a way to measure the differences in community structure for each landscape.

Forbes, A.E. and J.M. Chase. (2002) The role of habitat connectivity and landscape geometry in experimental zooplankton metacommunities. *Oikos* 96(3): 433-440.

The goal of this paper is to discover the effects that habitat connectivity and patch shape have on local and regional diversity. To get at the metacommunity dynamics of zooplankton the authors employ percent similarity (PS) to find a value for beta diversity (one minus PS). This value was then used in an ANOVA to test the effect of rate of connectivity.

Gibb, H., and D. F. Hochuli. (2002) Habitat fragmentation in an urban environment: large and small fragments support different arthropod assemblages. *Biological Conservation* 106: 91-100.

This paper uses ANOSIM (analysis of similarity—program that essentially tests for randomness of data from a similarity matrix using Bray-Curtis similarity index) to test differences in arthropod assemblages in two habitat types in various sized fragments.

Izsak, J., (1999) Notes on asymmetrical similarity indices. Oikos 84(2): 343-345.

Response to Kunin (1995) Author discusses behavior of indices related to Morisita's index in which the value is asymmetric (exceeding a value of one). Good for history of asymmetric indices in disciplines other than ecology.

Weltzin, J.F., N.Z. Muth, B. Von Holle, P.G. Cole. (2003) Genetic diversity and invisibility a test using a model system with a novel experimental design. *Oikos* 103(3): 505-518.

This is another application of similarity indices in the current literature. The authors use Jaccard's coefficient as a way to determine similarity of replicate communities created as high or low-densities of *Arabidopsis sp.* as well as to determine the similarity between "levels of richness" (richness was equated with genotype). The similarity measures where used to determine independence of treatments of density and richness.