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THE QUALITATIVE ANALYSIS OF POPULATIONS WITH BOOLEAN ALGEBRA, WITH APPLICATIONS TO PERTURBATON STUDIES.

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ABSTRACT

An extension of Boolean algebra partition theory is shown to be useful in the mathematical description of populations, using qualitative indices of species frequencies and non-numeric mean levels of relative species [illegible]dances. Boolean truth tables permit an evaluation of compositional changes in communities in time, and/or an evaluation of spatial heterogeneity and beta-diversity. This method is quick and simple, and produces easily interpreted [illegible]sults. Furthermore, this method is efficient for qualitative data, such as those obtained to evaluate the effect of an environmental perturbation, for example a pollution event.

INTRODUCTION

Qualitative methods have been used for some time in the analysis of natural communities (Daubenmire (1968), Mahoney (1970), Southwood (1978) and Williams (1970). Various propos[illegible]ls have been advanced to formalize the application of non-numeric mathematical methods for this [illegible]pe of problem. Of these methods, those using Boolean algebra offer interesting possibilities. The [illegible]eory of Boolean partition, for example, has been applied to study of the effects of an oil spill on an [illegible]tertidal community by Mahoney (1970). Using this technique, it was possible to clearly identify [illegible] changes of the component species of the community. Here, we propose an algebraic develop[illegible] [illegible] for prior analysis and an extension of this method to characterize natural communities through [illegible] relative frequency estimation, as well as a non-numeric estimation of the mean relative abundance [illegible] the component species of a community.

METHODS

[illegible] the pass of a pollution, the composition of species in the same area at different time intervals, [illegible] to show the environmental impact of a pollution. However, [illegible] areas at the same period of time, such as is generally the case for traditional studies of [illegible]. Finally, both types of sampling can be combined and provide, for example, in studies of succession.

Using methods of Boolean algebra, each sample is arranged in a truth table, in which all species present, [illegible] the rows and the columns, are used to represent the different levels of non-numeric abundance. In the [illegible]section of each row with each column, a Boolean numeral is placed, being either 1 or 0, following a relative [illegible] of "species-abundance". In this case, 1 is true and 0 is false. It should be remembered that the Boolean numerals 1 and 0 do not have a numerical significance, but only represent the binary choice between true and false. [illegible] samples are displayed in different truth tables, and are later joined to form a table which includes all of the [illegible] variation in the samples.

To illustrate this method, the data of Sinha (1988) on the effects of pollution on a freshwater community has [illegible] used as an example. In this study, all of the species present in summer and winter communities were registered [illegible] according to relative abundance levels before and after the pulse of pollution. To facilitate discussion, the categories [illegible] been reduced to three: (1) absent, (2) rare, and (3) common, which includes the original categories of frequent,

sensitive and abundant. These informations are summarized in Table 1. For each sample, two indexes of relative
abundance are given: rare and common (Table 1). The value of 0 in both columns indicates that both statements are
false, that is that the species is neither rare or common. In this case, therefore, the species is absent. The vector 01
associated with a species indicates that it is true that the species is rare in the sample. In this case, therefore, the species is absent. The vector 01 —
implies that the statement that the species is common in the sample is true. The vector 11 is a non-permissible
combination because it can not be true that a species is both rare and common at the same time in the same sample.
If samples are taken in different sites at the same time, the technique of truth table construction would be the same.

Petroleum and organic solvents are agents that can adversely affect freshwater ecosystems. However, the
component species of such communities can respond to perturbations, such as spills of these agents, in various
forms. Individuals species populations may not exhibit population changes after a perturbation, they can become
larger or smaller, or they can be completely eliminated. Starting from the information present in Table 1, we can
construct another truth table (Table 2), in summary form, the population responses to perturbations,
caused by polluting agents. In this table (Table 2) the Boolean vectors 00, 01 and 10, associate with each of the
component species, indicate, respectively, populations which did not change (00), which demonstrate a partial de-
cline (01) or which were completely eliminated (10). The vector 11 is likewise an illogical Boolean combination,
because it is contradictory. Nevertheless, we have adopted the convention that the vector 11 can represent a species
which was not present in the samples before the perturbation. This is also a useful convention to distinguish species
which did not demonstrate population changes, even though these were previously registered in relative abundance
data, from those species whose populations were not previously recorded in the samples before the perturbation,
and which consequently did not appear here. For example, the use of fertilizers can result in eutrophication, and the
matrices can be rearranged to consider this effect.

The information present in Table 2 can be rearranged to construct Table 3, in which all species which have the
same population responses are grouped. Using this table (Table 3), it is possible to rapidly obtain answers for explicit
questions, such as, what is the percentage of species present in both transects before the pollution event? In this case,
the solution is the sum of the number of species with vector responses of 1101 and 1111 of Table 2 divided by the
number of species present in both transects before the pollution event. In our example, this is 2/12 (1/24 = 8.3%). A
series of related questions can be further asked, and many of these are listed by Mahoney (1976). Community de-
scriptions according to species frequencies and abundances.

It is common practice in the area of natural communities according to ecological distribution and species
abundances. Generally, ecological distribution is given in statistical terms through the frequency index of each spe-
cies, defined as a proportion of the number of samples in which it occurred. In the case of Boolean truth tables, a
species is present in any sample in which the numeral 1 appears in any column of the sample table. Only when the
corresponding species vector contains uniquely of 00 is the species absent. Species abundance can be represented
semi-numerically by levels of relative abundance. For example, in Table 1, relative abundance levels are rare to com-
mon for the two samples before the pollution event. Usually, samples also must be quite large to detect variability within
the community, especially through the use of traditional parametric sampling techniques. In this example (Table 1),
the two transects (Reinaer & Wisconsin) given in the first columns of Table 1.

To obtain frequency indices, the samples in which the value 1 appears are summed, and this sum is then
divided by the total number of samples. Multiplying this index by 100, we obtain the frequency in percent. To esti-
mate the mean level of relative abundance, the following method can be used. The Boolean vectors 00, 01 and 10,
which represent the relative abundances of the species in each sample, can be considered binary expressions for the
digits 0, 1 and 2, which can be added for the samples in which the species is present. This sum can then be used to
represent a semi-quantitative estimation of relative abundance, F_r. If I_m is greater than 0 and less than 1, for any given
species, then the species can be considered as rare. If I_m is between 1 and 2, then the species is considered as
common. By using this simple rule, the corresponding columns in Table 4 can be estimated. There is a tendency
to a broad generalization of the community in terms of frequency or relative distribution or abundance, for an all
the mean species abundance as the sum of the number of samples in which the species appears, and not as [illegible]
the total number of samples. This effect could be taken into account; [illegible] this relationship between [illegible]
abundance of the species in each sample and in which it is present. We would further divide the levels of relative
abundance to produce more accurate estimates for each sample, which would consequently result in a larger variety of Boolean
vectors. Such scaling could be used, in both an arbitrary way and an understanding of relative abundance: [illegible]
of samples.

DISCUSSION

The information present in Table 4, compiled through simple methods, can be used as a com-
munity description. Several species (*Laminaria* spp., *Fucus spiralis* and *Pelvetia canaliculata*)
are present in the original histogram, but were not included in our analysis because of their low
biomass

number in the transects used. However, this is a problem of sampling methodology and not of the techniques we have discussed here.

In the methods we have proposed here, discrepancies may exist in the discrimination of levels of relative abundance between observers. However, this is a sampling problem and would affect any qualitative method. Our method is quick and simple and can be used in substitution of detailed and expensive qualitative samples, which are often impossible to obtain.

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TABLE 1- Species' relative abundances before and after a pollution event in a freshwater community. Data reformulated from SINHA (1986)

Abundances : c = common; r = rare

		TRANSECT							
		SUMMER				WINTER			
		pollution				pollution			
		before		after		before		after	
Code	Spices	c	r	c	r	c	r	c	r
01.	*Ankistrodesmus falcatus*	0	0	0	0	1	0	1	0
02	*A. hantzschii*	0	1	0	0	0	1	0	0
03.	*Chlorella vulgaris*	[illegible]	0	1	0	[illegible]	1	0	0
04.	*Scenedesmus armatus*	[illegible]	0	0	0	0	1	0	1
05.	*Amphora ovalis*	0	1	0	1	1	0	1	0
06.	*Navicula cuspidata*	1	0	1	0	1	0	1	0
07.	*Nitzchia* [illegible]	0	0	0	0	0	1	0	1
08.	*Synedra* [illegible]	0	1	0	1	1	[illegible]	0	[illegible]
09.	*Brachionus plicatilis*	[illegible]	0	0	0	0	1	0	[illegible]
10.	*Keratella cochlearis*	[illegible]	1	0	[illegible]	0	1	0	1
11.	[illegible]	[illegible]	1	0	0	1	0	1	0
12.	*Moina brachiata*	0	0	0	0	0	[illegible]	0	0
13.	*Ceriodaphnia Sp.*	1	0	0	[illegible]	[illegible]	0	1	0
14.	*Cypris* [illegible]	0	1	0	1	1	0	1	0
15.	*Stenocypris Sp.*	1	0	1	0	[illegible]	0	1	1
16.	*Filinia Sp.*	0	1	0	1	1	0	0	1
17.	*Cyclops Sp.*	0	1	0	1	1	0	0	0

TABLE 2 - Species response to pollution

Code	Species	TRANSECT SUMMER eliminated		WINTER eliminated	reduced
			reduced		
01.	*Ankistrodesmus falcatus*	[illegible]	[illegible]	[illegible]	[illegible]
02.	*A. braunii*	[illegible]	[illegible]	[illegible]	[illegible]
03.	*Chlorella vulgaris*	[illegible]	[illegible]	[illegible]	[illegible]
04.	*Scenedesmus* [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
05.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
06.	*Navicula* [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
07.	*Nitzschia hungarica*	[illegible]	[illegible]	[illegible]	[illegible]
08.	*Synedra* [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
09.	*Brachionus plicatilis*	[illegible]	[illegible]	[illegible]	[illegible]
10.	*Keratella cochlearis*	[illegible]	[illegible]	[illegible]	[illegible]
11.	*Rotaria* [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12.	*Moina* [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13.	*Ceriodaphnia* Sp.	[illegible]	[illegible]	[illegible]	[illegible]
14.	*Cypris* [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15.	[illegible] Sp.	[illegible]	[illegible]	[illegible]	[illegible]
16.	[illegible] Sp.	[illegible]	[illegible]	[illegible]	[illegible]
17.	*Cyclops* Sp.	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 3 - Boolean vectorial response of each species

Boolean vectorial response of species SUMMER eliminated	reduced	WINTER eliminated	reduced	Number of species	Species Code
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	05 06 13 [illegible] [illegible] [illegible] 16
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] 17
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	02 04 07
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	09 12

TABLE - 4 Community description based upon distribution and relative abundance of the component species

Species Code	TRANSECT					
	SUMMER		WINTER		Frequency	Relative
	common	rare	common	rare	%	Abundance
01.	0	0	1	0	50	common
02.	0	1	0	1	100	rare
03.	1	0	0	1	100	common
04.	0	0	0	1	50	rare
05.	0	1	1	0	100	common
06.	1	0	1	0	100	common
07.	0	0	0	1	50	rare
08.	0	1	1	0	100	common
09.	0	0	0	1	50	rare
10.	0	1	0	1	100	rare
11.	0	1	1	0	100	common
12.	0	0	0	1	50	rare
13.	1	0	1	0	100	common
14.	0	1	1	0	100	common
15.	1	0	1	0	100	common
16.	0	1	1	0	100	common
17.	0	1	1	0	100	common

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