SYSTEMS RESEARCH INSTITUTE
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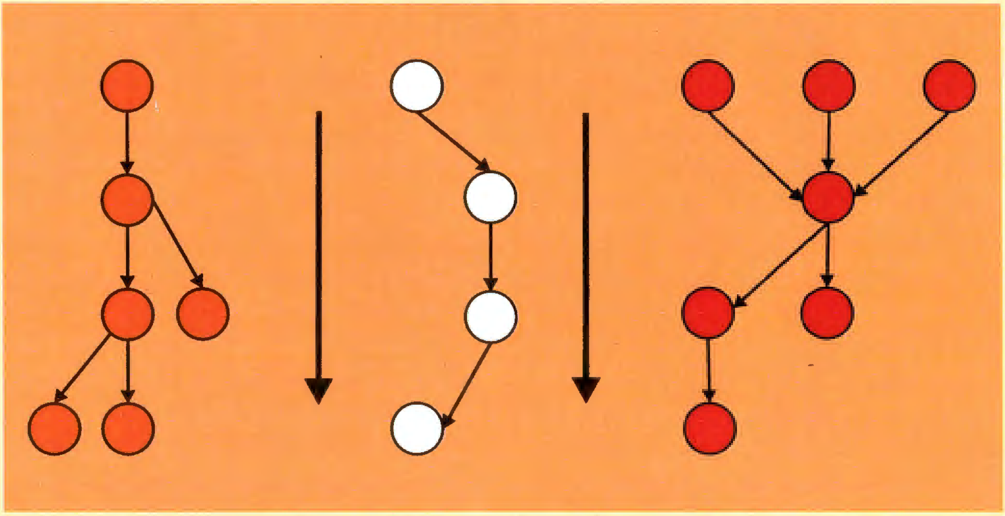
MULTICRITERIA ORDERING AND RANKING:
PARTIAL ORDERS, AMBIGUITIES AND APPLIED ISSUES



Jan W. Owsiński and Rainer Brüggemann
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This book is the outcome of the international workshop held in Warsaw in October 2008 within the premises of the Systems Research Institute. All papers were refereed and underwent appropriate modification in order to appear in the volume. The views contained in the papers are, however, not necessarily those officially held by the respective institutions involved, especially the Systems Research Institute of the Polish Academy of Sciences.

ISBN 83-894-7521-9
EAN 9788389475213

Technical editing and typesetting:
Jan W.Owsiński, Anna Gostyńska, Aneta M.Pielak

Applications and Comparisons

Multicriteria Ordering and Ranking: Partial Orders, Ambiguities and Applied Issues
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Partial Order Theory for Assessing the Sensitivity of Planktonic Algae to Anthropogenic Disturbances in Regulated Lakes

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The use of phytoplankton as a quality indicator has been adopted by the European Water Frame Directive issued in 2000 (WFD 2000/60CE), which has widen the connotation of biological survey by shifting the attention from an anthropocentric view of natural systems towards a more 'eco-centric' view. Within this framework, this paper offers an insight into phytoplankton communities living in hydrologically regulated lakes. Data come from an extensive survey carried out by Cesi Ricerca during 2004 in nine Italian reservoirs which are exploited at different levels for power production. Phytoplankton communities are investigated at the order level. The authors followed a multi-dimensional approach with the goal of identifying the level of sensitivity of algae communities to anthropogenic disturbances. Results highlight two groups of algae *orders*: one consisting of algae with their own regulation mechanisms, which do not follow the mechanism of reservoir regulation. The other consisting of algae which adapted to anthropogenic disturbances and can be considered robust to exploitation. This approach, if applied in similar water bodies, may be used for optimizing the experimental effort providing methods for ecological classification which are cost-effective, as explicitly recommended in the 2008 European call on Environment.

Keywords: phytoplankton, artificial lakes, partial order, Hasse diagram, sensitivity analysis, averaged ranks, similarity analysis

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1. Introduction

European policy for water protection has been clearly outlined within the frame of the Directive 2000/60 (Water Framework Directive). Besides many other important concepts, the Directive has introduced for the first time in the European legislation the idea that water bodies are not only a physical space where water is stocked or transported, but complex ecosystems, where physical, chemical and biological characteristics are mutually related and therefore can be altered by any kind of pressure.

The WFD identifies also the necessity to assess the ecological quality of water bodies by assessing the status of their living communities compared to the pristine, natural condition of a water body of similar geomorphologic characteristics. This request leads in turn to the necessity of interpreting biological data deriving from water body surveys not as merely indicators of some other water characteristic (typically chemical quality or eutrophication) but as an expression of the ecological richness of the water body itself.

For this latest aspect the implementation of the WFD at European level is facing many obstacles especially as regard to lakes and coastal waters, for which a general lack of acknowledged and standardized methods for ecological classification is well recognised. Even less knowledge exists regarding the behaviour and ecological characteristics of artificial water bodies, for which the hydrological regime can be highly variable due to power production.

In this frame an experimental study was set up during 2004 with the goal to develop and propose a methodology for the ecological classification of artificial lakes based on biological information. Data set were gathered in nine Italian reservoirs which are exploited at different levels for power production. The reservoirs are characterised following the DPSIR model (Drivers, Pressures, State, Impact, Response). Abundance data of phytoplankton species have been the object of previous studies to relate them to environmental data using multivariate methods, both directly with Canonical Correspondence Analysis and indirectly with Multidimensional Scaling (Jongman et al., 1995). Results of this preliminary analysis (Garofalo et al., 2005) highlighted differences among the reservoirs and in particular put in evidence the cases where pressure, water quality and biological assemblages were not in accordance.

In this study the goal is to investigate the response of algae assemblages to the different pressures acting on the artificial lakes.

2. Surveys

In Italy the number of artificial lakes amounts to more than 500, most of which have been built in the last century for hydroelectric generation. A general need of research focused on this typology of water bodies is still felt by the scientific community. Recently the Italian water legislation has included large reservoirs within the survey network of local environmental agencies.

For the purpose of gaining an insight into the ecological characteristics of reservoirs, a total of nine hydroelectric reservoirs are here investigated. Following the eco-regional approach suggested by the WFD, the selected reservoirs are all located in the Apennine region (Central Italy), trying to minimise differences in biological responses due to geo-climatic drivers. Main geo-morphological characteristics and location of study sites are reported in Table 1. A comment is in order: some of the selected reservoirs are hydrologically connected, both naturally, because of their localization on a common watershed, or artificially, through pipelines, meaning that not only water quality but algae populations may be influenced. This is the case of Pontecosi, which receives waters also from Gramolazzo; Borgiano, receiving waters from the upstream reservoir Polverina and from Fiastra through a pipeline. Suviana and Brasimone as well are connected, the latter being a pumped storage reservoir where water is back-pumped from Suviana during low energy demand hours, generally night time. This net of connections are taken into account in the following when commenting results (Sect. 5.2).

External pressures acting upon the water ecology were considered in terms of pollutant loads from the watershed and of hydrological disturbance due to the water withdrawal operated by the power plant. Potential pollutant load has been assessed according to the IRSA methodology (Barbiero et al., 1991), which is based on the computation of the total Equivalent Inhabitants (EI) of the watershed upstream the lake, taking into account anthropic presence, in terms of inhabitants, human activities and of the presence of industrial and agricultural activities. Estimation of equivalent inhabitants was based on official reports by the Italian National Institute of Statistic as fully described by Garofalo and Gilli (2005). Daily withdrawal data during 2004 have been provided by the dam managers (Garofalo and Gilli, 2005).

To investigate the ecological status of the reservoirs, three field surveys were carried out in April, June and September 2004. All reservoirs were investigated within a ten day period during each sampling season, to guarantee almost the same climatic conditions for all sampling sites. Within each reservoir two to four measure points were located along the longitudinal axis of the water basin from tail to dam, to account for possible longitudinal gradients in water quality. For each measure point vertical profiles of chemical-physical parameters were measured with a multi-probe, water and plankton samples were taken at different depth from the surface (3 to 6 sampling points along the water column). Sampling depth were established on field depending on the water stratification assessed by temperature and oxygen profile.

Water samples were analysed for algal nutrients (TP, TN, phosphates, nitrates ammonium, silicates) and chlorophyll concentration; phytoplankton was analysed for abundance in terms of both density (n°cell/ml) and biomass (mm^3/m^3) at species level.

Table 1. Selected regulated Italian lakes and their geographical location

Lake name	**Abbreviation**	**Watershed**	**Altitude (m a.s.l.)**	**Volume (m^{3}x10^6)**	**Mean depth (m)**
La Penna	P	Arno	203	10	6.1
Gramolazzo	G	Serchio	601	3.4	9.7
Pontecosi	PCOSI	Serchio	311	3.0	8.7
Brasimone	BRA	Reno	845	6.4	11.8
Suviana	SUV	Reno	470	43.8	29.6
Mignano	MIG	Arda	328	15.9	17.0
Fiastra	FS	Fiastrone	640	21.7	24.4
Polverina	PV	Chienti	400	5.8	7.8
Borgiano	BOR	Chienti	297	5.05	7.7

3. Attributes to describe external pressures on lakes

In order to investigate the response of phytoplankton communities to external disturbances, the first step of the analysis consists in selecting variables which describe possible impacting factors on reservoirs. Among available variables, five attributes are selected as disturbance indicators, as shown in Table 2. These attributes describe hydrological and anthropogenic pressure on selected reservoirs and are all intended to show a clear orientation with respect to algae blossoming.

Hydrological attributes, which are all related to the Weekly Refill Period WRP, are meant to describe the level of artificial regulation of the lake. WRP is defined as the ratio between the lake volume and the outflow discharge, both computed as weekly average. This means that, for regulated reservoirs, the lower the values of WRP the higher the disturbance. Since our intent is to include attributes positively related to the 'distance' of the lake from theoretical natural conditions, we chose to reverse WRP attributes, which are then transformed to be directly related to the level of artificiality of the reservoir.

Attribute EI is considered to be a rough indicator of the trophic load on lakes. it is supposed to be directly related to the lake distance from natural conditions. Total phosphorous has been selected as a direct indicator of blossoming potential.

Table 2. description of hydrological and anthropogenic attributes

Attribute #	Attribute name	Attribute description
1	WRP(.5)	Median of Weekly Refill Period (WRP)
2	WRP(.1)	10th percentile of WRP
3	WRP(.9)	90th percentile of WRP
4	EI	Number of equivalent inhabitants (x1000)
5	Ptot	Total phosphorus concentration

4. Phytoplankton communities and blossoming description

The phytoplankton data set deriving from the survey is composed by a total of 220 different species and tens of abundance data (3 seasons x 9 lakes x 2-4 sampling sites x 3-5 depth). For the intent of this analysis it was necessary to reduce the dimension of algal data set with some preliminary aggregations.

Vertical variability was managed by mixing samples taken at different depths, then the average biomass concentration of the different sampling sites within the lake was computed for each species. Time aggregation was obtained by considering for each species the maximum value registered among the sampling periods, with the aim of better focusing on species blossoming. In this way only one abundance value was used to characterise each species blossom in each lake.

To reduce the number of different species within each lake a further aggregation was obtained by summing up the abundance of species belonging to the same algal *order*, also according to recent similar studies (Salmaso et al., 2006). In other words *order* level data is eventually considered in the analysis.

Order names are recoded as shown in Table 3. Note that to differentiate the term 'order' referring to phytoplankton communities from the term 'order' referring to partial order theory, the former is in *Italic* style within the text.

Table 3. Algae *order* names and abbreviations

***Order* name**	**Abbreviation**
Centrales	Centr
Chlorococcales	Chloroc
Chroococcales	Chrooco
Cryptomonadales	Cripto
Desmidiales	Desmid
Euglenales	Eugle
Nostocales	Nosto
Ochromonadales	Ochro
Oscillatoriales	Oscill
Pennales	Penna
Peridiniales	Peri
Synecochoccales	Syne
Volvocales	Volvo
Zygnemales	Zygne

Due to the typical high variability of phytoplankton communities, numerical values of densities are classified into six classes according to percentiles (see Table 4).

Table 4. Classification of algae *order* density *d*

Algae *order* density	0 (absence)	$\leq d_{50}$ (median)	$\leq d_{65}$	$\leq d_{80}$	$\leq d_{95}$	$> d_{95}$
Class #	0	1	2	3	4	5

The presence of fourteen different algae *orders* is recorded in investigated reservoirs.

	BOR	**BRA**	**FS**	**G**	**MIG**	**P**	**PCOSI**	**PV**	**SUV**
WRP(.5)	-7.8	-2.6	-87.9	-5.7	-42.1	-19.5	-1.8	-9.9	-13.2
WRP(.1)	-3.90	-2.20	-48.00	-2.60	-7.40	-1.50	-0.50	-4.40	-9.10
WRP(.9)	-21.70	-4.60	-248.00	-54.50	-122.20	-68.90	-13.10	-19.50	-21.60
EI	41.419	18.826	2.054	3.057	2.789	618.018	30.024	22.784	11.165
Ptot	15.18	5.88	7.88	9.1	8.35	77.63	13.06	17.64	6.68
Centr	3	1	3	2	1	3	3	4	1
Chloroc	1	1	1	1	1	3	3	2	1
Chrooco	0	0	1	0	0	2	1	0	0
Crypto	3	1	2	2	1	4	2	4	1
Desmid	1	0	0	1	1	1	1	1	0
Eugle	2	1	1	1	1	4	5	2	1
Nosto	0	0	0	0	0	3	0	0	0
Ochro	4	1	3	0	3	1	3	5	1
Oscill	1	1	4	0	0	4	2	3	1
Penna	3	1	4	2	1	2	5	2	1
Peri	4	1	3	2	2	5	4	3	1
Syne	0	0	1	1	0	1	0	0	0
Volvo	1	1	1	1	1	5	2	1	1
Zygne	0	0	0	0	0	3	0	0	0

Figure 1. Transposed data-matrix

The final data-matrix has dimension 9 x 19 with lakes on rows and attributes on columns. Attributes describe hydrological pressures (attributes # 1 to # 3), anthropogenic pressures (attributes # 4 and # 5) and phytoplankton blossoming (attributes # 6 to # 19) (see Fig. 1 which shows the transposed data-matrix for formatting reasons).

5. Methods and applications

5.1. Hasse Diagram Technique

Due to the high intrinsic multivariate nature of biological populations and to the lack of well defined theoretical models to describe phytoplankton in regulated lakes, the approach is here to adopt partial order techniques. Partial order techniques are descriptive methods which derive from Discrete Mathematics. The special partial order relation, namely that of the product order (Davey and Priestley, 1990) regards the multivariate character of a data matrix. The method, based on the product order, is known as Hasse Diagram Technique (HDT). HDT has many connecting points with multivariate statistics (Welzl et al., 2001). In explorative multivariate statistics the analyst has often the need of studying data with respect to 1. variability, 2. distances and 3. order relations (scaling, measuring, ranking). When partial order techniques come into play various connecting point can be highlighted between the above statistical issues and partial order tools (Brüggemann and Welzl, 2001). But over statistical multivariate methods for ecological and environmental data, they have the advantage of being very simple and application oriented at the price of a purely ordinal view on the data. HDT does not need to fulfil distributional conditions, as it is not based on parameterized models, nor they have to minimize any loss function. Still HDT often provides straight and simple representations of data and their internal structure.

Due to these features, in the last decades partial order tools have been used for empirical studies specifically for environmental issues, where data is primarily obtained by real observations, often not very numerous nor replicable, and with space and time complex distributions (for some recent publications, see Annoni and Brüggemann, 2008; Carlsen and Brüggemann, 2008; Restrepo et al., 2008; Voigt et al., 2006, and also Brüggemann and Carlsen, 2006). There are also regular international workshops, where theory and applications of partial order in environmental sciences and chemistry are discussed. For further information contact one of the authors.

A theoretical sketch of HDT is due in the following subsection.

5.2. A first insight into data: Hasse diagrams

The starting point of our investigation is the poset. A poset will be denoted by $(P, \leq)$, where P is a set and $\leq$ is a subset of PxP which is an order relation on P, i.e. a reflexive, antisymmetric and transitive relation. Its elements $(a,b) \in \leq$ are written as $a \leq b$ (Neggers and Kim, 1998). Since in the following the order relation is clear from the context, the poset will be simply denoted by P. Two elements a and b of P are called comparable if $a \leq b$ or $b \geq a$; otherwise they are called incomparable and we write $a \parallel b$. The equivalence relation $a = b$ is defined as the condition where $a \leq b$ and $b \geq a$. If $a \leq b$ and $a \neq b$ then a is said a successor of b. We say that b covers a, denoted as $a \prec b$, if $a \neq b$, $a \leq b$ and there exists no $c \in P$ such that $a \leq c \leq b$. A chain of a poset P is a subset of P in which every two elements are comparable; dually, an antichain is a subset of P in which every two elements are incomparable (De Loof and De Meyer, 2006). Relation $\prec$ is called the covering relation and a poset can be conveniently represented by the so-called Hasse Diagram (HD) where $a \prec b$ if and only if there is a connecting line upward from a to b. In a HD vertices are elements of the set P and edges represent the covering relation. Minimal and maximal elements of a HD are defined as respectively elements which do not cover and are not covered by any other element in the diagram. Isolated elements are those which are not connected to any other element of the diagram and are both maximal and minimal elements. These basic concepts of Partial Order Theory are substantially the only tools needed to comprehend the analysis.

Investigated lakes are to be considered as elements of the set P on which a partial order relation is induced in this case by the nineteen numerical observed attributes. Lakes x and y are comparable, say $x \leq y$, if for every attribute a_j, j=1,..., 19, the observed value of a_j on x, $a_j(x)$, is lower than or equal to the corresponding value observed on y, i.e. $a_j(x) \leq a_j(y)$ with at least one strict relation. With this order relation P is a poset. Of course many different posets can be derived by using different subsets of the complete set of observed attributes.

In this specific context, our focus is to compare various posets, deriving from different subsets of attributes, for measuring their mutual 'distance' in terms of similarity/dissimilarity in order to extract the influence of pressure indicators on algae communities. The first poset to be analyzed is the one induced by pressure attributes only which is called Pressure Poset *PP* (Fig. 2). Two minimal elements FS and SUV are present and, due to attribute polarity, they are the lakes with the least external pressure. At the other end of the diagram four maximal elements are recognizable: BOR, P, PCOSI and PV, while BRA is an isolated element with features of its own. The longest chain is the one which connects FS to MIG, G and PCOSI with FS lake as the least impacted reservoir in terms of investigated attributes. The HD is coherent with a rough subdivision of sites in two groups: at one side the group formed by FS and SUV which are characterized by high retention time and an overall good water quality; at the other side a more numerous group represented by smaller lakes with shorter residence time and an overall worse water quality. Site BRA, which features a very good water quality and a low residence time shows no comparability with other lakes.

The poset induced by algae *orders* represents another characterization of the lakes, Algae Poset (Fig. 3). As reasonable, many more incomparability relations are present in this case: phytoplankton attributes are more numerous and also more variable than pressure attributes. The equivalence of BRA and SUV in the diagram is coherent with the tight hydraulic connection between these two reservoirs (water is pumped back from SUV to BRA during night-time), indicating a similar algae *order* composition in the two connected lakes. All other comparability relations in the poset induced by algae *orders* seem not to be related to the hydrological net discussed in Section 2. This suggests that phytoplankton populations are not influenced by the type of artificial connections between lakes.

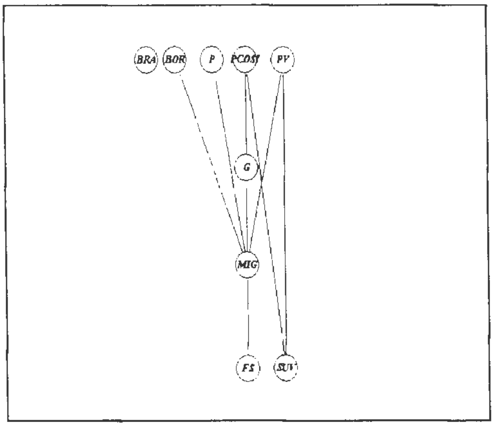

Figure 2. Pressure Poset, that is the poset induced by hydrological and anthropogenic attributes only

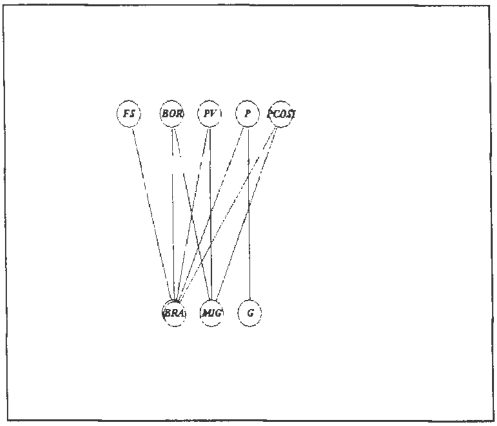

Figure 3. Algae poset, that is the poset with phytoplankton attributes only (SUV and BRA equivalent)

5.3. Individual influence of algae *orders*: sensitivity analysis

The idea is to combine one phytoplankton attribute at a time to the pressure poset *PP* to identify individual influence of the algae on the order structure of lakes determined by pressure parameters alone. If an algae *order* does not change the order relations in *PP*, it means that it fits the structure of *PP*. This can be seen as a kind of adaptation of that algae *order* to external pressures. On the contrary, if an algae *order* totally dismantles the *PP* structure, it means that it follows mechanisms unrelated to observed pressure indicators. A measure of the influencing strength of each phytoplankton *order* may then be interpreted as single sensitivity of the algae to external pressures on lakes. In short we want to set-up a 'ruler' for algae sensitivity to hydraulic regulations and anthropogenic pressures included in the study.

For measuring individual algae sensitivity the basic idea is to quantify a dissimilarity between two posets. The dissimilarity between two posets is computed by the **W** matrix (Brüggemann et al., 2001) whose elements are related to the cardinality of successor sets within the two posets. Any cell (i, j) $(i \neq j)$ quantifies dissimilarity between two posets obtained by respectively the subset with all the attributes but attribute i and the subset with all attributes but attribute j.

Table 5. 'Univariate effect' of algae *orders* on the pressure poset *PP*

Case #	**Algae attribute**	**attribute #**	**W-value**
1	No algae	1 to 5	-
2	Centr	6	2
3	Chloroc	7	0
4	Chrooco	8	4
5	Cripto	9	1
6	Desmid	10	0
7	Eugle	11	0
8	Nosto	12	0
9	Ochro	13	4
10	Oscill	14	5
11	Penna	15	5
12	Peri	16	2
13	Syne	17	5
14	Volvo	18	0
15	Zygne	19	0

Dissimilarity between posets is then quantified on the basis of a particular metric which involves cardinality of Hasse diagram subsets. By using **W** matrix values, we compare the pressure poset *PP* to each poset obtained by considering pressure attributes together with one algae *order* at a time ('enlarged' *PP*). So in our case we are interested only in one cell of matrix **W**, which quantifies dissimilarity between poset *PP* and the 'enlarged' *PP*. Table 5 shows W-values of interest for each single phytoplankton *order* added to the original *PP* poset.

Algae *orders* with highest W-values are called 'highly influencing' *orders* because they are responsible for the highest deviations from the pressure poset. These are: Oscill, Penna and Syne. At the other end of the algae ruler, algae *orders* with W = 0 can be considered 'non influencing' algae *orders*. They are Chloroc, Desmid, Eugle, Nosto, Volvo, Zygne. Their inclusion in the set of attributes does not influence the order structure of *PP*. All other algae *orders* may be considered of medium-low influence.

With the aim to eliminate possible ordinal correlation among the three high impact *orders*, W-values are computed for all possible subsets of Oscill, Penna and Syne, i.e. for seven nonempty subsets. This analysis may be denoted as multivariate sensitivity analysis. Results show that the pair (Penna, Syne) is the minimum subset of high impact *orders* which has the highest impact on pressure poset (W-value = 7).

In addition, it has been evaluated the presence of ordinal correlation effects between the group of medium-low impact *orders* and the pair (Penna, Syne), which may possibly increase the W-value. The scheme of this sensitivity analysis is as follows: all possible subsets of the set of medium-low impact *orders* are added to the minimum perturbing subset (Penna, Syne), in total 63 subsets (*order* Oscill is now considered as medium-low impact order). Results shows that the maximal perturbing subset is the triple (Penna, Syne, Ochro). These are the phytoplankton *orders* which mostly dismantle the order structure of lakes based on pressure attributes only.

The behaviour of these highly influencing phytoplankton *orders* may be due to a twofold reason: 1. they may prefer perfectly opposite conditions, which from our point of view represent more natural conditions, or 2. they may obey to their own regulation mechanisms which cannot be described by our rough pressure indicators. To verify the two hypotheses a similarity analysis is performed.

5.4. Highly influencing algae orders: similarity analysis

To evaluate the kind of differences between pressure poset (*PP*) and the one induced by highly influencing algae *orders* (*HIP*) a similarity analysis is adopted. The basic idea is straight and simple: if posets *P*1 and *P*2 are to be compared, the number of a certain type of order relation of $(a,b) \in P1$ (comparability, equivalence, incomparability) which is transformed in another type of order relation

$(a,b) \in P2$ is counted. Specifically, the types of transformations considered in a similarity analysis for two elements a and b $(a,b) \in P1$ and $(a,b) \in P2$ are shown in Table 6.

If the similarity analysis is used to compare two separate sets of attributes, various information can be derived. For example it is possible to find out whether attributes included in the second poset destroy the order relations of the first one with completely conflicting relations, that is if most transformations are antitones. In this condition, the interpretation is that attributes of the second poset obey to a reversed mechanism. Note in this context the methodological approach recently proposed by Sørensen et al. (2005) to analyse conflicts.

We compare the pressure poset *PP* to the poset which includes only the triple of highly influencing algae *orders* (Penna, Syne, Ochro). Calculations are performed with a new software package named PyHasse ('Hasse based on programming language Python'), under development by one of the authors (R. Brüggemann).

Table 6. Type and name of transformations counted in a similarity analysis between posets

Name of transformation	Order relation in $P1$	Order relation in $P2$
Isotone	$a < b$	$a < b$
	$a > b$	$a > b$
Weak Isotone	$a < b$ or $a > b$	$a = b$
	$a = b$	$a < b$ or $a > b$
Equivalence	$a = b$	$a = b$
Antitone	$a < b$	$a > b$
	$a > b$	$a < b$
Indifferent	$a > b$ or $a < b$ or $a = b$ or $a \parallel b$	$a \parallel b$
	$a \parallel b$	$a > b$ or $a < b$ or $a = b$ or $a \parallel b$

Computations show that percentage of isoton is 14%, of antiton is 8% and of indifferent is 78%. No weak isotone or equivalence transformations are present. As the percentage of transformations which are antitones is very low we cannot say that the triple (Penna, Syne, Ochro) is anti-correlated, in terms of ranks, with pressure attributes. Still it is interesting to note that lake FS (Fiastra) mostly contributes to the antitone counts (three out of six). This means that Fiastra lake, being characterized by relatively low levels of pressure attributes (see poset of (Fig. 2), shows the higher abundance of these three phytoplankton *orders*.

5.5 Robust algae *orders*: averaged ranks and similarity analysis

On the other end of the 'algae ruler', we already mentioned the presence of a group of algae *orders* which does not affect the order structure induced by pressure parameters. They are in total six *orders*: Chloroc, Desmid, Eugle, Nosto, Volvo and Zygne. These algae *orders* show a behaviour which is consistent with pressure attributes: may they be defined as robust to hydrological regulations and anthropogenic pressures for the investigated lakes? The following analysis aims at answering this question. To this aim a further characterization of highly influencing and not influencing algae *orders* is performed by an analysis of correlations of averaged ranks (Brüggemann et al., 2004).

Partial order theory is often useful in various applicative fields, but the fact that no linear order is generally found may reduce its appeal especially within non experts in the field. Many attempts have been done to circumvent the issue, for example by introducing averaged ranks of the elements of a poset based on the set of linear extensions (Patil and Taille, 2004; Lerche et al., 2003). A linear extension of a poset *P* may be thought as a poset which contains all the elements of *P*, preserves all their order relations and may be represented by linear Hasse diagrams. For a more formal definition of extensions and linear extensions see for example Neggers and Kim (1998).

From the set of linear extensions an averaged rank, *Rkav*, may be computed. However, as the number of linear extension increases dramatically with the number of objects (approximately with $N!$, N being the number of objects), a straightforward procedure is often not feasible. The approach adopted here is to compute an estimate of the averaged rank, as proposed by Brüggemann et al. (2004). The estimate of averaged rank of object x is mainly based on the number of objects ranked below x (successors of x) and objects ranked above x (predecessors of x). For further details refer to Brüggemann et al. (2004).

Following this approach, we compute averaged ranks of lakes for three different posets: 1. the poset induced by not influencing algae *orders* (P_{low}); 2. the poset induced by pressure attributes alone (*PP*) and 3. the one induced by highly influencing algae *orders* (P_{high}). Results are shown in Fig. 4 while Table 7 shows correlation coefficients on averaged ranks.

Table 7. Rank correlations for posets P_{low}, PP and P_{high}

		$Rkav(P_{\mathrm{low}})$	$Rkav(PP)$	$Rkav(P_{\mathrm{high}})$
$Rkav(P_{\mathrm{low}})$	Pearson Corr.	1	.839**	.590
	Sig. (2 tails)		.005	.094
$Rkav(PP)$	Pearson Corr.	.839**	1	.382
	Sig. (2 tails)	.005		.311
$Rkav(P_{\mathrm{high}})$	Pearson Corr.	.590	.382	1
	Sig. (2 tails)	.094	.311	

As expected, there exists a significant correlation between averaged ranks of the posets PP and P_{low}; whilst no correlation exists between averaged ranks of PP and of P_{high}. A direct comparison between posets P_{low} and P_{high} is due in Figure 5.

Even if these six orders appear to be 'robust' to external pressures, they can still show a different behaviour with respect to hydrological regulations (WRP attributes, attributes # 1 to # 3 of Table 2) and anthropogenic loads (EI and Ptot, attributes # 3 and # 4 of Table 2). To this aim, separate similarity analyses are performed for evaluating the difference between P_{low} and the poset induced by hydrological attributes P_{hydro}, on one hand, and the difference between P_{low} and the poset induced by anthropogenic attributes P_{anthro}, on the other hand. Results are shown in Table 8 and indicate a slightly stronger effect of hydrological regulation than anthropogenic load on robust algae *orders*.

Table 8. Similarity analysis to separately evaluate the effect of hydrological and anthropogenic attributes on low impact phytoplankton *orders*

	Isoton	Antiton	Weak isoton	Indifferent	Equivalence
P_{low} vs P_{Hydro}	0.42	0.11	0.11	0.36	0.0
P_{low} vs P_{Anthro}	0.67	0.03	0.03	0.28	0.0

6. Concluding remarks and comparison with similar studies

Knowledge about the relationship between pressures and composition of biotic communities in lakes is not as clear as for rivers. Whilst ecological assemblages and functionality of rivers is mainly driven by water current, in lentic water many mechanisms may contribute to determine the phytoplankton assemblage which appear highly variable notwithstanding the apparent stability of the ecosystem (Scheffer et al., 2003).

Average ranks for NOT influencing algae *orders*

OBJECT	*P*	*S*	*U*	*N*	Rkav
P	0	7	1	9	8.9
PCOSI	0	7	1	9	8.9
PV	2	6	0	9	7
BOR	3	5	0	9	6
G	4	3	0	8	4
MIG	4	3	0	8	4
BRA	6	0	0	7	1
FS	6	0	0	7	1
SUV	6	0	0	7	1

Average ranks for pressure attributes

OBJECT	*P*	*S*	*U*	*N*	Rkav
P	0	2	6	9	7.5
PCOSI	0	4	4	9	8.3
PV	0	3	5	9	8.0
BOR	0	2	6	9	7.5
G	1	2	5	9	6.0
MIG	5	1	2	9	2.5
BRA	0	0	8	9	5.0
FS	6	0	2	9	1.3
SUV	2	0	6	9	2.5

Average ranks for highly influencing algae *orders*

OBJECT	*P*	*S*	*U*	*N*	Rkav
P	1	3	4	9	6.7
PCOSI	0	3	5	9	8.0
PV	0	3	5	9	8.0
BOR	0	3	5	9	8.0
G	2	0	5	8	2.3
MIG	4	2	2	9	3.8
BRA	5	0	1	7	1.1
FS	0	5	3	9	8.6
SUV	5	0	1	7	1.1

P= # of predecessors
S= # of successors
U= # of incomparabilities
N= $(S+P+U+1)$
Rkav= $(S+1)*(N+1)/(N+1-U)$

Figure 4. Averaged ranks of lakes

In many studies algal presence has been seen as a whole, for the effects that an increasing biomass might influence water chemical quality. Up to now the quality of lakes has been considered by assessing their trophic level, taking into account indicators of the potential for algal growth (phosphorous, nitrogen), of the presence of algae (chlorophyll) and their impact on water quality (dissolved oxygen and turbidity).

Due to the new request arisen by the WFD some efforts have been recently made to investigate phytoplankton presence in lakes considering their assemblages and seasonal succession in relation to the presence of anthropogenic disturbances. Even less studies are available dealing with artificial lakes and with the hydrological disturbance due to the variable flow regime induced by the hydropower plant operation.

Within this perspective, our research aims at getting an insight into some mechanisms that regulate phytoplankton communities in regulated reservoirs. Specifically we try to evaluate the effect of some external pressures on the algae populations aggregated at *order* level. We use different techniques recently developed for the analysis of partially ordered sets to set-up a kind of 'ruler' for measuring algae sensitivity to impacting factors on reservoirs. Two groups of algal *orders* are recognizable: one of *orders*, which seem to follow their own regulation mechanism, another, less numerous, of more 'robust' *orders*, which show a more adaptive behaviour.

Although results of this analysis cannot be sustained by the comparison of similar studies up to now, some interesting observation can be drawn comparing our conclusions to the results of Salmaso et al. (2006). In this study the authors, investigating the phytoplankton presence in some great natural Italian lakes, are able to observe that some algal *orders* show the tendency of growing in more oligotrophic lakes (Ochromonadales and, to a lesser extent, Prymnesiales) and a stronger correlation is observed for other algal *orders* with eutrophic conditions (namely Tribonematales, Volvocales, Chlorococcales, Nostocales and, at least partly, Desmidiales and Chlamydomonadales). Interestingly in our case the set of algae *orders* which show a stronger development in highly disturbed lakes includes Chlorococcales, Desmidiales, Nostocales, Volvocales, whilst the set of more sensible algae *orders* includes Ochromonadales as indicated also by Salmaso et al. (2006). Likewise our results, they are also able to observe that some *orders* are more homogeneously distributed in the lakes regardless their trophic level.

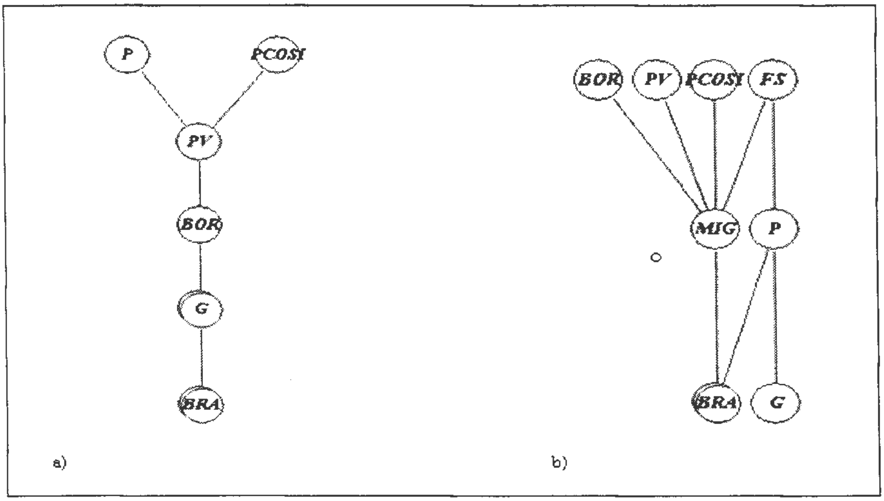

Figure 5. a) Poset induced by not influencing algae orders (BRA = SUV = FS; G = MIG) and b) Poset induced by highly influencing algae orders (BRA = SUV)

Even if it is not possible to draw further conclusion about the influence of hydrological regime on the phytoplankton assemblages in regulated lakes, the methodology used in this study appear to have a potential for application in the field of water ecology when special attention has to be given to the analysis of multiple and complex variables on biological assemblages.

Summarizing, the methodology may be described as follows:

1. find data on biological systems at an observational level of interest;
2. introduce pressure indicators, corresponding to the DPIRS concept (Drivers, Pressure, State, Impact, Response);
3. find subsets of low and of high sensitivity with respect to pressure indicators by means of Partial Order Techniques;
4. identify possible mechanisms of (adverse) actions by subdividing the pressure indicators in appropriate subgroups.

Acknowledgements

Data used in this study has been produced within the projects financed by the Research Fund for the Italian Electrical System under the Contract Agreement between CESI RICERCA and the Ministry of Economic Development - General Directorate for Energy and Mining Resources stipulated on June 21, 2007 in compliance with the Decree n.73 of June 18, 2007.

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This book is a collection of papers, prepared in connection with the 8th International Workshop on partial orders, their theoretical and applied developments, which took place in Warsaw, at the Systems Research Institute, in October 2008. The papers deal with software developments (PYHASSE and other existing software), theoretical problems of ranking and ordering under various assumed analytic and decision-making-oriented conditions, as well as experimental studies and down-to-earth pragmatic questions.

ISBN 83-894-7521-9
EAN 9788389475213