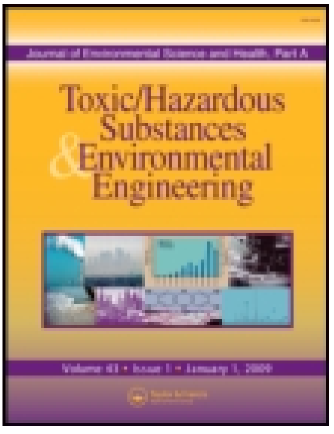

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Some propositions on the nomenclature of aquatic ecologies for water treatment

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SOME PROPOSITIONS ON THE NOMENCLATURE OF AQUATIC ECOLOGIES FOR WATER TREATMENT

Key Words: Biocoenosis, Linnaean taxonomy, ecological engineering, boundarisized ecological complexity, self-purification system

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INTRODUCTION

Conventional chemical and biological water treatment systems exist in recognised forms surrounded by a wealth of literature detailing operational capacities. This has perpetuated the myth that water treatment, naturally an ecological process can be simplified by excluding complexity above a physicochemical or microbial level. If natural systems are to provide a realistic alternative to such unit process approaches, there is a need to develop a method for defining their ecological component (i.e. the ecologies or biocoenoses which comprise the technology itself).

This paper details a largely theoretical investigation into boundarisized ecological complexity. The research examines the role that ecological engineered systems can play in the development of integrated water management frameworks. An interdisciplinary stance is taken, allowing the ecological complexity of such

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systems to be boundarisized by the social/management issues, which define water treatment as a human activity. We describe the formulation of a water treatment design or planning tool based on a 'bottom up approach' where the key aquatic organisms and biocoenoses, which comprise the water 'treatment', are catalogued. A problem of taxonomy is encountered, it's main features described, and an alternative approach suggested and explored. The classifying of functional individuals is found not simply to be a question of species identification using the Linnaean taxonomic hierarchy. The design of viable natural water treatment systems is examined through the formulation of ecologies via a structuring of biology. The complex features of ecologies (diversity, variety, networks etc.) are seen to confer functional properties on the water treatment systems (performance, response to shock loading etc.) The paper concludes that nutrient cycling by organisms as components of functional biocoenosis pathways is the primary biotic factor, which defines an ecological treatment (self-purification) capacity and suggests a way of classifying organisms in this context.

THE PROBLEM

Contemporary treatment processes for domestic and industrial sewage have evolved primarily from the requirement to decrease effluent biochemical oxygen demand (BOD_5 concentration) and so protect receiving waters. It is not surprising, therefore, that the performance of a wastewater treatment plant is gauged by this BOD_5 decrease and is thus designed primarily upon the basis of BOD loading. Advanced sewage treatment methods are process variations which exceed this simple BOD_5 elimination and deal with "biologically refractory materials (collectively expressed as COD) and phosphorous and nitrogen." (Mudrack and Kunst 1985). These methods remove more contaminants from wastewater then are taken out by conventional biological treatment. Examples of advanced sewage treatment technologies include; bacterial nitrification to oxidise ammonia to nitrate, and chemical-biological treatment for phosphorous removal using aluminium or iron coagulants.

"Natural" or ecologically engineered technologies comprise those systems, which utilise ecological processes as an option to simply incorporating biological activity via biotechnological and chemical manipulation. To a certain extent these are already being used in water treatment particularly to provide economic treatment for small rural communities and for industrial waste treatment prior to discharge into watercourses. Natural systems provide a technological alternative to simply using conventional water treatment. Although it should be noted that contemporary wastewater treatment technologies are not of themselves environmentally damaging, their use can be criticised for a number of reasons (Guterstam and Todd, 1990)

- They generate large amounts of sludge, which is often toxic and is thus environmentally stressful if disposed of by ocean dumping, land filling, spreading, or incinerating.
- They employ environmentally damaging chemicals e.g. aluminium salts to precipitate out solids and phosphorous chlorine.
- They fail to remove metals and synthetic organic chemicals.
- They are costly in terms of financial capital, energy and labour.
- Engineering difficulties are still incurred with the elimination of fine suspended solids, colloidal matter and dissolved substances.

If alternative water treatment systems based on ecological engineering principles are to be both effective and efficient (in terms of both function and utility), engineers and planners will require a set of suitable design tools. The area of how one actually approaches the design of natural treatment systems for water management is poorly understood. Previous research has shown that media such as wetlands, lakes and ponds do have a treatment potential. However, this knowledge is often only an emergent finding from studies focused primarily on limnological, ecological or biological phenomena. This paper approaches the problem of designing natural systems for water treatment in order for them to support integrated treatment processes where the ecotechnological potential of such systems is harnessed, in addition to their biochemical and biological attributes. The fact that natural systems are already the recipients of traditional water treatment activity means that their "self–purification" capacity is already being harnessed (all- be- it generally from beyond the physical confines of the treatment works). However, the role which ecological systems play in changing water quality is largely undefined and subsequently their role as water quality changing systems frequently remains unperceived.

STRUCTURING VIABLE ECOLOGIES – THE PROBLEM OF CLASSIFICATION

The research reported here seeks to support the development of design tools for water quality management through engineered ecologies by defining the technological potential of the biophysical processes integral to water quality change. The approach taken involves investigating the bi-directional interaction between water quality and ecological change. This bi-directional relationship between the abiota and biota of a system represents the frequently cited "self-purification capacity" of aquatic systems. This is a more complex phenomenon to describe at an ecotechnological level than at a biotechnological one. At a simple level "self-purification is the microbial breakdown of complex organic molecules into simple organic molecules together with processes of dilution and sedimentation" (Mason 1996). Whilst at an ecological engineering level where homeostatic mechanisms are occurring on a macro level it can be referred to as "the Odum phenomenon of self organisation…which Ma and Yan refer to as self purification" (Mitsch and Jørgensen 1989) This phenomena of "self purification" or "self-organisation" is a central one when looking to structure valid ecologies to achieve certain levels of water quality change or treatment.

The structuring of viable ecologies involves investigating the interrelationship between the abiota and biota of a system and requires an interdisciplinary approach, mapping between knowledge domains within the natural sciences i.e. between the biochemical, biological and ecological concepts relevant to water treatment and ecological engineering. As with much interdisciplinary research, the task of mapping between disciplines, especially closely related ones, can be achieved by a consideration of the taxonomies used to describe system structure and functionality. When looking at ecologically engineered systems there is a need to classify the organisms and groups of them (biocoenoses, ecologies) in functional terms as part of an environmental change hierarchy. In this case the environment is water quality and the organisms are those which belong to the fresh water systems involved. To do this necessitates the adaptation of traditional taxonomies in a way dependent on context. It involves several levels of mapping, firstly between the scientific fields of biology, biochemistry and ecology, and secondly between these and the sociological drivers of water use. This paper deals explicitly with the former mapping exercise and explores how the biochemistry of a system can be mapped onto the ecology of the same system using, as a mapping function, a non-Linnaean classification structure.

Investigating the structure of valid ecologies requires defining the organisms, which comprise them. These are usually classified using the traditional Linnaean taxonomic hierarchy (Linnaeus, 1740). Although this classification is generally an appropriate one for identification of reproductive isolates (evolutionary types), it cannot provide all the relevant biological information necessary for ecological engineering purposes. Having said this, the Linnaean taxonomy has stood the test of time well and is essential for the identification and restocking of aquatic systems. Table 1 elaborates.

The "self-purification capacity" of a natural system/ecology is not defined simply by its biological functionality but also by the principle ecological processes of transformation which arise by the variety of biological types comprising it. If the use of trophic levels is taken as a principle example of a functional ecological taxonomy based on nutrient transformation then the Linnaean biological classification does not relate to functional ecological classification. Although at the most inclusive of Linnaean taxa, the two Kingdoms 'plantae' and 'animalia' do coincide with an organism's ecological status as either producer or consumer, at the least inclusive level (i.e. species) an infinite number of taxa can be categorised as a single trophic level. For instance all plant species are classed as primary producers although a few such as pitcher plants are also secondary

TABLE 1
Advantages and Disadvantages of Using the Linnaean Classification for Ecological Engineering

Advantages of using Linnaean Taxonomy		Disadvantages of using Linnaean Taxonomy
Identifies reproductive isolates i.e. species for restocking systems	BUT	Does not classify/differentiate between life stages of those species
Reflects functionality in terms of evolutionary morphology	BUT	Does not necessarily reflect functionality in ecological engineering terms
Differentiates between a myriad of types	BUT	Does not elucidate with respect to interactions between organisms

consumers. This indicates that the isolated use of such biological and ecological classification is inappropriate for defining the biota of ecologically engineered systems.

FINDING A CLASSIFICATORY SOLUTION

The method employed in this research to map between the biochemical, biological and ecological levels involved is one of taxonomic manipulation where the reclassification of the organisms comprising the biota of freshwater systems allows their short-term functionality as engineers of their environment (abiotic and biotic) to be classified as opposed to their long-term evolutionary functionality. There is, as always some overlap between the two. To define an ecology requires defining the individual types of organisms which comprise it. However, at a biological level, organisms are defined using the Linnaean taxonomic system, whilst on an ecological level they can be defined by their trophic position along a food chain, be it a grazing or detritivorous one. Classifying an organism's functionally in terms of the effect it has on its biochemical environment is not always the same as classifying it relative to its evolutionary history. Combining simple ideas from traditional Linnaean classification and ecological classification goes some way to developing taxa which represent different functionalities in terms of solid dynamics and oxygen demand in fresh water systems These new taxa form part of a new interdisciplinary classification system or "ecotaxonomy". The evolution of an "ecotaxonomy" can be followed by investigating the formulation of a classification system via three simple stages. Each of these stages produces a complete taxonomic structure, which can be used to define organisms ecotechnologically with respect to their water quality transition potential.

As an example, we take the context of organically loaded waters where the parameter chosen to define the system's biochemistry is its biochemical oxygen demand which is itself closely related to the presence of solids, both suspended and settled. The most obvious way to reclassify fresh water organisms with respect to their ecotechnological functionality is to define them as gross oxygenators or deoxygenators of a system. This actually relates to their Linnaean kingdom status, which delineates between plants and animals. A third taxon, "air gulpers", is used to classify those air breathing aquatic organisms such as cat fish which gulp air at the surface, and surface attachers such as insect larvae. Such organisms are more tolerant of low dissolved oxygen levels. The deoxygenating and "air gulping" animalia component can then be further subdivided in terms of whether they directly or indirectly remove solids from the water column. This factor is important when ecologically engineering a system, as it will indicate ecological interdependence. Direct solid removers will either be detritivorous organisms or primary consumers who feed upon the algal component of the system. Indirect solid removers will coincide with the higher trophic levels (i.e. secondary consumers and above) and thus will rely upon stocking the system with relevant direct solid consumers. In this way the first level of the ecotaxonomy is a simple hybridisation of traditional biological and ecological classifications. Only five ecotypes or ecospecies are derived from such a simple set of distinctions, namely

- Gross oxygenators
- Gross deoxygenating direct solid removers

- Gross deoxygenating indirect solid removers
- Air gulping direct solid removers
- Air gulping indirect solid removers.

This is obviously not enough to successfully define an organism's specific ecological engineering niche with respect to BOD and solid reduction and the taxonomy can be further refined by the introduction of spatiality within the system i.e. by introducing the organism's position in the water column. This can be most simply done by introducing three basic positions for the animal/gross deoxygenating component; surface, mid-water and benthic. Although fauna is not static, an organism can be classified in terms of where it spends the majority of its time (where it feeds). This then helps define which organisms can co-exist as part of a healthy food web/water treatment hierarchy. The plant/gross oxygenator component can be divided slightly differently into algal, submergent macrophyte, surface macrophyte and emergent macrophyte components. This taxonomic development then produces a total of sixteen ecotaxa (ecospecies).

If the Linnaean taxonomic system classifies the most exclusive taxon (i.e. species by merit of reproductive isolation) then the ecotaxonomic development uses biochemical exclusion. Stage 3 of ecotaxonomy development is achieved by adding another spatial component of biochemical tolerance. It does this by incorporating a very simple biotic index, namely the saprobic (saprobien) index (Kolkwitz and Marsson, 1902). This biotic index (as shown in Table 2) is specific to organic pollution and hence to the parameters defining the ecotaxonomy. It relates the stages of organic pollution to specific kinds of organisms. The addition of these four saprobic types to delineate further taxa generates a sharp increase in complexity resulting in 64 ecotaxa.

The aim of this exercise is to define organisms in terms of their contribution to a water body's ecological self-purification potential. This requires interpreting organisms as functional parts of a whole, the whole being the ecology or biocoenosis to which they belong, rather than individual products of evolution. The ecotaxonomy is principally an example of taxonomic manipulation whereby the parts of traditional taxonomies(both biological and ecological) relevant to the

TABLE 2
The Saprobic Index

Saprobic Stage	Process	Water Quality Class	
Polysaprobic	Primary process of decomposition	IV (no O_2, H_2S)	+veDO*
a-Mesosaprobic	Secondary process of decomposition	III (<50% O_2 no H_2S)	--ve BOD
b-Mesosaprobic	Progressed mineralization	II (>50% O_2)	
Oligosaprobic	Completed mineralization	I (O_2 saturated)	

DO*- dissolved oxygen

reduction of solids and BOD from the water mass, are taken and mapped to generate a simple functional taxon. The structure of the new taxonomy is asymmetrical and not hierarchical, unlike the Linnaean taxonomic system. An example of the application of ecotaxonomy 3 can be found in Figure 1.

APPLICATION OF THE NEW TAXONOMY TO THE DESIGN OF NATURAL SYSTEMS FOR WATER TREATMENT

This taxonomic development contributes to the idea of structuring valid self-purifying ecologies for wastewater treatment by:

- Defining organisms in terms of their potential self-purification functionality and by relating them to one another in terms of an ecological treatment hierarchy based upon solids and nutrient transfer.
- Dividing organisms in terms of the spatiality of their feeding position in the water column, which reflects also upon their ecological functionality i.e., what other organisms they encounter.
- Dividing into saprobic types it gives some indication of the biochemical tolerance/intolerance of organisms to the parameter, which dictates their functionality i.e. BOD (biochemical oxygen demand).

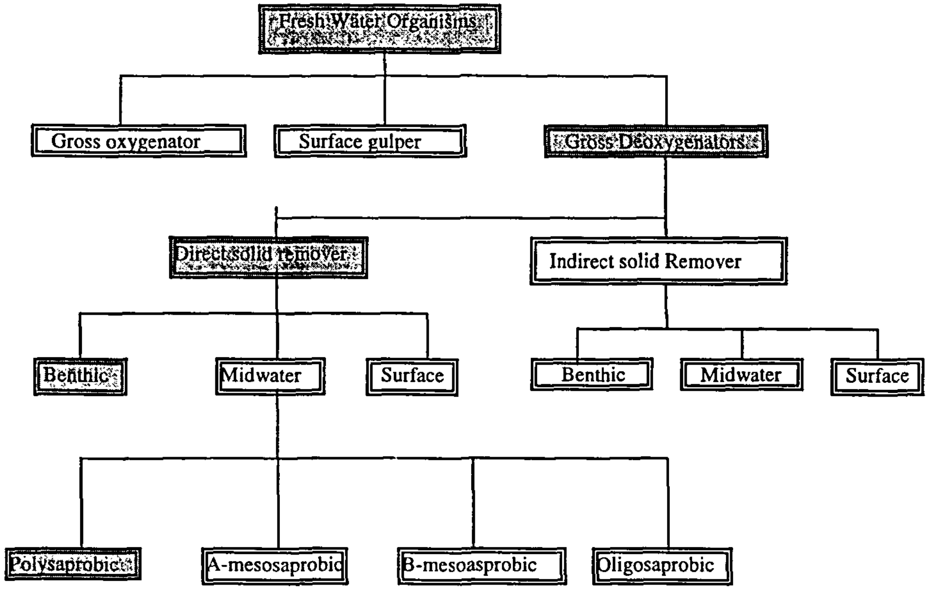

FIGURE I
Classification of a polysaprobic, benthic, direct solid removing, gross deoxygenator such as *Tubifex Tubifex.*

- Enabling Linnaean specific types and biomonitors to be classed, during the creation of data bases to detail case study findings, in accordance to a gross water quality change parameter.

Some examples of ecotaxonomic groups are depicted in Table 3.

Obviously many Linnaean species share the same ecofunctional niche. If the number of Linnaean species in a system is plotted against the number of ecofunctional types this gives a graphical distribution shape which is characteristic of a viable ecology where the plant (oxygenating) component is dominated by a variety of algal groups and the deoxygenating animal component is dominated by a variety of direct solid removing organisms.

Finally, we can identify a set of strengths and weaknesses of the suggested approach which help us to both locate its potential application to real world problems and suggest possible developments of the work itself. The first point to note is that an ecotaxonomic approach attempts to classify an organism's

TABLE 3
Examples of Reclassification Using the Developed Ecotaxonomy

Linnaean Specific	Common Name	Ecospecific
Tubifex tubifex	Tubificid worm	Polysaprobic,benthic feeding, direct solid removing gross deoxygenator
Oscillatoria planctonica	Blue/green algae	a-mesosaprobic, algal, gross oxygenator
Branchnchionus rubens	Wheel animalcule (rotifer)	a-mesosaprobic, mid-water feeding, direct solid removing, gross deoxygenator
Keratella cochlearis	Wheel animalcule (rotifer)	b-mesosaprobic, midwater, direct solid removing,,gross deoxygenator
Daphnia hyalina	Water flea	a-mesosaprobic, midwater , direct solid removing, gross deoxygenator
Cyprinus carpio	Carp	a-mesosaprobic, benthic feeding, indirect solid removing gross deoxygenator
Chlorophyta tetraedon	Green algae	b-mesosaprobic, algal, gross oxygenator

(eco)functionality in terms of key transformations intrinsic to energy transfer by distinguishing between ecological interrelationships central to energy transfer. Secondly, the approach facilitates the transfer of knowledge between the different fractions of the biological sciences relevant to ecotechnology and enables persons who are not *au fait* with biological classification to realise the ecological engineering functionality of different types of organisms. In this sense, the work reported above also raises questions about the skills required to support a more diverse strategy for water management. Water treatment via the control and regulation of an ecology requires knowledge and skills which are currently under-represented in many water management institutions. The integration of zoologists, ecologists, and botanists into such organisations is a pre-requisite for the effective and safe management of natural systems for water treatment. The largely institutionally imposed boundaries thrown up between waters for human use and those which are considered part of the 'environment', are both artificial and restrictive.

Weaknesses of the approach include the fact that it cannot, as yet, operate in isolation of phylogenetic taxonomic systems such as the Linnaean binomial nomenclature or modifications of it. To a certain extent it also only represents a static picture of organism ecofunctionality (e.g. plants are classed as 'gross oxygenators' because even though they respire at night this is outweighed by the effect of their photosynthetic activity during the day). If, however the blooming of algae means that plant respiration at night outweighs the daily photosynthetic capacity then the taxonomic framework needs to be extended to include a distinction between say, 'blooming' and 'non-blooming' types. Perhaps more significantly, the approach is limited to context specific applications because an organism's ecofunctionality depends on the scale of the ecologically engineered system (its boundarisized ecological complexity). A clear example of this is if the functionality being classified is restricted to activity in the water column and benthos, in this case if a system has floating macrophytes such as water hyacinths or duckweed (*Lemna* sp) then these have to be classed as gross deoxygenators, despite being plants. This is because they do not oxygenate the water column and by their shading effect actually prevent the growth of oxygenating algae.

CONCLUSIONS

The approach described above provides a framework in which relevant ecological and biological data can be amalgamated. It generates a simplistic but 'user friendly' descriptive device for non-biologists concerned with the functioning of ecologically engineered systems. Although not yet a design tool for water quality management, ecotaxonomic classification could be used, at certain levels, to inform planners involved in the design of natural treatment systems. Future developments include the addition of more ecofunctional groups and the use of cycles of specific nutrient transfer such as nitrates and phosphates to further refine the classification system

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