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Brigid M Browne

**ECOTECHNOLOGY AS INTERDISCIPLINARY METHOD:
ECOLOGICAL ENGINEERING OF WATER QUALITY**

**Innovation and Technology Assessment Unit
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Ph.D

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CRANFIELD UNIVERSITY

Innovation and Technology Assessment Unit

International Ecotechnology Research Centre

Ph.D THESIS

Academic Years 1996-2000

Brigid Browne

**ECOTECHNOLOGY AS INTERDISCIPLINARY METHOD:
ECOLOGICAL ENGINEERING OF WATER QUALITY**

Supervisor: Dr. R.A.F. Seaton

March 2000

Dedication

***This thesis is dedicated to my family ; Sean, Logan, Cathy and
Bridey (Brigid senior).***

***It is also dedicated to the memory of my dad, Robert Alexander
Browne 'Bob' and my grand-dad Arthur Richard Fielder 'Dick' who
were responsible for many
"happy, funny times".***

Acknowledgements

To all those who have helped, Thankyou.

Abstract

The principle objective of the work is to explore an ecotechnological, interdisciplinary approach to studying 'natural', in ecologically engineered terms, systems. This requires the investigation of two sub-objectives. The first of which is to develop an assessment method for investigating the bi-directionality between water quality (biochemical) and ecological change as a socially directed biophysical or 'natural' technology. Supporting this first sub-objective is a second one which offers an innovative approach, in the form of developing a new classificatory framework or 'ecotaxonomy', which uses the concepts of hierarchy and emergence in describing the biological components (*bios*) of such 'natural' systems.

Central also to the research is a case-study which relates to an issue of perception in the way that treatment processes at a water treatment works are generally regarded as separate from the treatment processes of water in 'natural' watercourses and the aquatic ecologies endogenous to them. Wastewater-fed aquaculture systems are a principle example of an ecological engineered treatment system or socially directed biophysical technology, which bridges this perceptual divide. Such an aquaculture system is used to test the new taxonomic framework.

As a result of the development of a conceptual model and the hybrid classification exercise several interesting observations are made. Firstly the way in which the ecotaxonomy as a hybridization of traditional biological and ecological classification enables the systems biochemistry to be mapped to its ecology. Secondly the utility of 'inter' taxonomic systems generally as mapping functions to facilitate knowledge transfer and interdisciplinary research. Thirdly the creation of a classification systems which allows, by merit of it's structure, for the phenomenon of emergence.

Other interesting side issues are raised such as the role of 'objective' as opposed to 'natural' biological classification systems and further implications on the effect of changing biological taxonomic structure are discussed, with particular reference to principle ecological theories such as the diversity-stability hypothesis and the nature of biological variety and functional diversity in natural systems generally.

If social needs, such as water treatment, are to 'harness' natural biological systems then these properties of ecotechnology need to be further developed.

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Chapter 1.

The Nature of 'natural' Systems

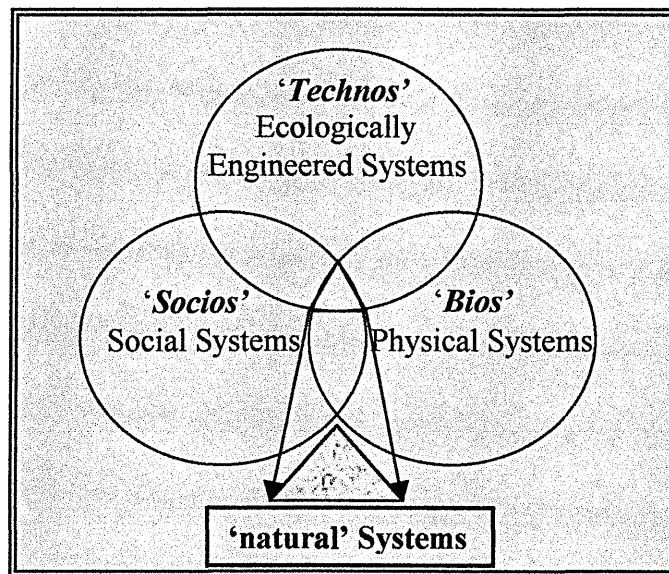
"Nature, make it a small, not a capital N and nature applies to almost everything that is nameable" (Trinh T. Minh-ha, 1996).

1.1 Ecotechnology and Ecological Engineering of 'Natural' Systems

The word 'system' is a ubiquitous one. Aside from its obvious role as a designator of procedure, the term 'system' as a noun, whether considered real or 'perceived' (Checkland, 1976), can enable a mind to distinguish between parts and wholes. Although this is a personal process there is a relatively new branch of 'science' which attempts to deal with such wholism (structure and organisation) as a concept and this can be termed 'complexity theory' (Allen, 1997; Lewin, 1995; Hiett, 1996). For the purpose of this thesis it is sufficient to define 'system' in general terms as

"An interconnected set of elements that is coherently organised around some purpose. It is (by merit of such organisation) more than the sum of its parts and can exhibit, adaptive, goal-seeking, self-preserving, and evolutionary behaviour." (Meadows et. al. 1993, adapted from von Bertalanffy, 1951).

Fig. 1.1 Locating 'natural' Systems in this Thesis

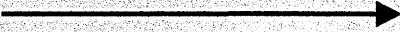


The tendency, even in ecological engineering circles (Chapter 2), to perceive humans as removed from nature and, singularly, as the engineers of systems, is in this research countered by looking at both the biological and the ecological feedback of relevant aquatic systems in addition to their biochemical characteristics. This is done, primarily, by using exercises in functional biological classification. It is then, in this way, suggested that humans are simply the engineers of other organisms which are, in actuality, the 'ecological engineers' of the physical system.

There is also some confusion between the terms ecological engineering and ecotechnology (Section 2.1) and this research attempts to distinguish between them. In order for an ecotechnological research approach to be taken the work needs to include, in addition to an investigation of a physical system, some technological and/or sociological input.

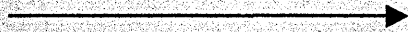
This research describes a singular cognitive journey but is concerned with the development of interdisciplinary tools for both the individual researcher and researching teams (section 10.8). The thesis explores the “*epistemology of technology*” (Seaton, 1999 pers. com.) using as a context not only the bi-directional (Section 1.5) relationship between abiotic and biotic components of ‘natural’ systems (specifically organically loaded freshwater systems) but also the way in which knowledge about such systems can be used via an appreciation of the role of classification. This can be approached from different levels/scales and Table 1.1 illustrates this.

Table 1.1 Three Levels of Researching Methodologies for Investigating ‘natural’ Systems

Biotechnological Approach	Ecological Engineering Approach	Ecotechnological Approach
(Not to be confused with biotechnology.)This can be designated the ‘micro’researching level as it involves investigating the relationship between organisms, their components and the environment. It can also be termed ‘bios’ the ‘basic biological level’. It should be noted that complex ecological interactions do occur in microbial communities	This can be designated the ‘meso’ researching level as it requires investigation into complex interactions between organisms and an environment effected by human activity. This can be perceived as a more complex biological level the inclusion of a human component directly in the system enables the emergence of a new level i.e. from bios to technos.	This can be described as the ‘macro’ researching level as it enables the investigation of complex interactions between organisms and their environment including not only human physical activity but also human perception, technology and the epistemology of the system/technology.
<div> <div> The traditional mechanistic, reductionist researching method used to investigate Natural systems. </div> <div>  </div> <div> The more holistic researching methodologies associated with exploring human/social systems </div> </div>		

Although this table uses terms and delineates levels rather arbitrarily it does represent a hierarchical organization in that the simplest levels are encapsulated by more complex ones. Table 1.2 illustrates a more real (in physical terms) hierarchy and one, which is also relevant to the following research.

Table 1.2 Three Levels of the Perceived ‘natural’ System

Biological Level	Ecological Level	Ecotechnological Level
Relates to organisms as types separate from one another and their environment. The organism is the whole.	Investigate the organism (can include humans) as interacting parts of a whole comprised of both living /biotic*and nonliving /abiotic* parts	Includes the human component in the form of perception/knowledge about the biological system of which the mind is a part
Reductionist/mechanistic		Holistic / natural

Interactions of systems at the lower less complex levels (whether real or perceived) of organisation can create unanticipated developments at the higher more complex levels of organisation. This phenomenon can be described as ‘emergence’

“The concept of emergence refers to the phenomenon whereby causes at one hierarchical level generate qualitatively new effects at a level of greater complexity” (Lewes, 1874; Mill, 1904; Morgan, 1933; Hadfield 1997).

1.2 Interdisciplinarity, Mapping Functions, Hierarchy and Emergence

This section addresses four concepts, which are central to the framework of this research, namely

1. Interdisciplinarity
2. Mapping Functions
3. Hierarchy
4. Emergence

The centrality of these concepts relates to the fact that issue driven research generally requires approaching a study from multiple levels and perspectives and thus involves aspects of hierarchy (Pattee, 1978) and emergence (Morgan, 1933, Hadfield, 1997). Such multiplicity or complexity also generally necessitates transversing the traditional academic lines of disciplinarity and in this way requires an interdisciplinary researching approach (Sections 1.2.1, 2.4, 10.2). Interdisciplinary research requires a level of mapping between the relevant knowledge domains (or the relevant parts of disciplines/subdisciplines) and this can be facilitated by the use of mapping functions (Section 1.2.2).

These four concepts are actually interrelated and so the following descriptive subsections will include some reference to all of them and they will reappear regularly in the following chapters.

Firstly the idea of interdisciplinarity, although described in detail in Chapter 2 requires a brief introduction at this point as it is central to the conceptual framework of the thesis.

1.2.1 Introducing Interdisciplinarity

It is unsurprising that a study of ‘natural’ systems would require input from the ‘natural’ or ‘biological’ sciences. Biology itself is no longer a single discipline but comprises numerous sub-disciplines/disciplines such as biochemistry, genetics, zoology and ecology, this idea is returned to in Chapter 2 (Table 2.3). These often describe the same biological phenomena but in different ways because the characteristics/attributes of interest may differ between the sub-disciplines. A cell, for instance, will be of interest to a microbiologist for a whole different ensemble of reasons than it would be for say a geneticist. The former might be obsessed with microtubules* and cytoplasmic* structure whilst the latter would more than likely be concerned only with nuclear material. Often in the biological sciences such interest or sub-disciplines coincide with

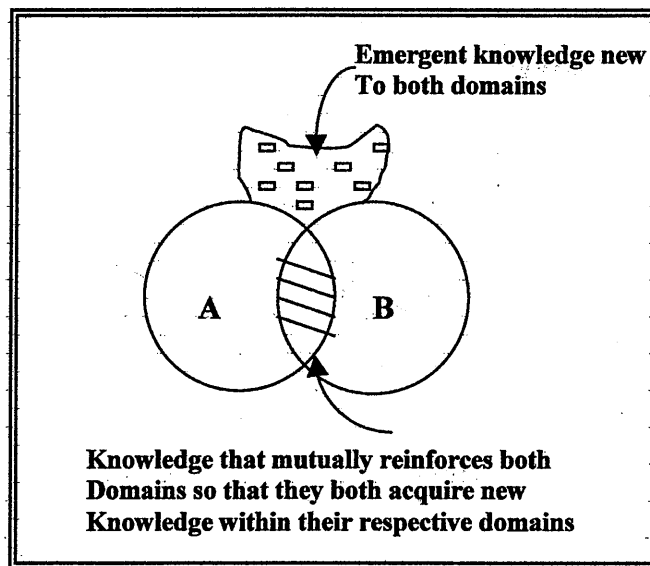
an appreciation based upon the physical scale of the system but this is not always the case. In this thesis the principle phenomenon of interest is the 'organism' as a whole and the way in which different organisms are classified in the biological and other sciences. Figure 2.3 in the next chapter illustrates this.

This idea of multiple definitions of a phenomenon is not peculiar to the biological sciences. It can occur where any research, especially issue driven / policy relevant studies, incorporates ideas from two or more disciplines or knowledge domains.

"In the context of academic research members of two or more disciplines (or, as in an organisation, an individual competent to operate within two disciplines) may operate on a common phenomenon. Where this occurs the interaction results in mutual benefits in the acquisition of knowledge within the existing disciplines. This approach can be described as 'interdisciplinary'" (Seaton, 1997).

Figure 1.2 shows such an interaction between two knowledge domains labelled A and B.

Fig 1.2 Interdisciplinary Association (Seaton and Jeffrey 2000)



"The generation of knowledge outside the interacting disciplines can be described as emergent knowledge since it also arises from the co-evolution of the two knowledge domains. Some researchers describe this form of knowledge generation in interdisciplinary research as 'transdisciplinary' (O'Rourke 1995)." (Seaton and Jeffrey 2000)

When during the course of objective, issue driven research different disciplines overlap whilst describing or classifying identical phenomena then this overlap should coincide with those characteristics or attributes of the phenomenon which are of central interest to the research context.

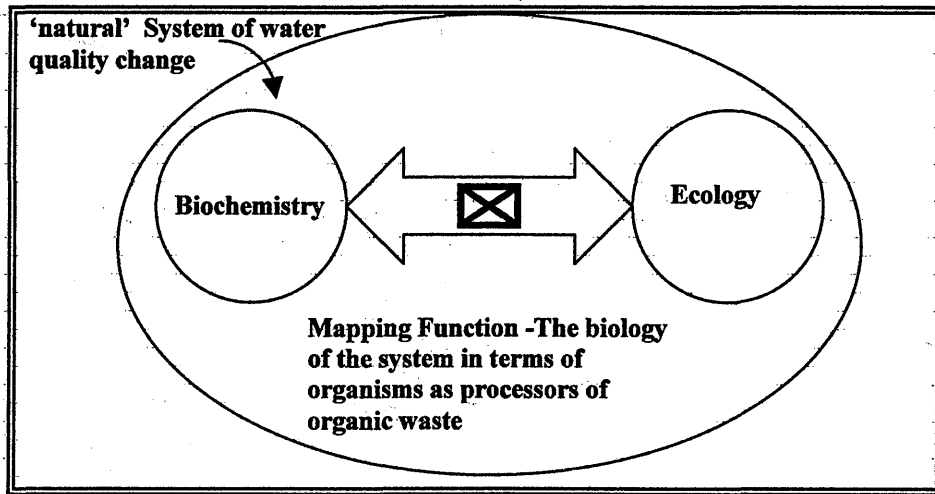
In this thesis the phenomena of interest are the organisms which interact with one another and their environment and the attributes of interest are those which produce a specified change in water quality. In this way the biochemistry of a physical system is mapped to its ecology, that is the two are inextricably linked within a system of self-purification (Chapter 5). The actual/physical intermediary or “*mapping function*” (Seaton, 2000) which facilitates this self-purification process are the ‘organisms’ which have, for the benefit of this thesis, been chosen as the principle biological phenomenon of interest. This is shown in the following Figure 1.3.

1.2.2 Mapping Functions

“*Mapping functions*” (Seaton, 1997) can also be used to facilitate knowledge translation between disciplines and in this context it is not the organisms which constitute this but a method of classifying them which enables the biochemistry of the system to be mapped to its ecology. The reclassification of organisms in this case not only maps the biochemistry to the ecology of the system it also creates a taxonomy which can at some levels map the biology (organisms in singular terms) to the ecology of the system (the interaction of organisms with themselves and their environment). The new classification system or ‘ecotaxonomy’ is detailed later in Chapters 8 and 9.

Fig 1.3 Using Biology as a Mapping Function

Mapping the process of water quality change in a ‘natural’ system.



Natural systems can for the conceptual purposes of this thesis be perceived as comprising the following hierarchical levels which each generate qualitatively new effects at the more complex hierarchical levels (Figure 1.4).

1.2.3 Hierarchy

This thesis is therefore preoccupied with mapping vertical linkages created when a ‘bottom up’ interdisciplinary approach is taken to researching a complex socially

directed biophysical* or 'natural' system. The hierarchical levels (real and perceived) comprising this system are detailed in Table 1.3.

In his thesis Julian Park (1993) and detailed in a paper (Park and Seaton, 1993) mapped both the vertical and horizontal linkages associated with another 'natural' system context, one of sustainable land based production, namely silvoarable agroforestry. He was able to map in this bi-directional fashion because he incorporated socio-economic theory alongside scientific theory. He was also modelling the actual processes involved rather than a classification of them.

Table 1.3 Scaling Hierarchical Levels 'Real' and 'Perceived'

<u>MAPPING LEVELS</u>	<u>THE ACTUAL 'REAL' SYSTEM BOUNDARY</u>	<u>THE 'PERCEIVED' RESEARCHING / EPISTEMOLOGICAL SYSTEM BOUNDARY</u>
<u>Micro</u>	The physical/biological level of a 'natural' system which can be described in terms of its physical level of organisation i.e. its physical, chemical, biochemical, biological and ecological structure.	In this way a system is described at a particular organisational level using the relevant discipline/sub-discipline. The integration/mapping of different scientific attributes /characters from the different disciplines, knowledge domains or mindsets creates the emergent 'meso' level
<u>Meso</u>	The inclusion of physical characteristics from beyond the actual physical system being studied such as the inclusion of human effect on a system of other organisms from the 'micro' level.	The hard technological level whereby a system is described by integrating the interaction of the sciences (microlevel) and the engineering in hard technological terms of a 'natural' system when some aspect of human nature is perceived as an integral part of the design process. The macrolevel can emerge from this when non-physical human elements are introduced into the system.
<u>Macro</u>	The inclusion of non-physical human attributes to researching a 'natural' physical system. For example the incorporation of ideas on the learning procedures or perceptions about the study system. These 'soft' system attributes will relate to the 'hard' aspects/characteristics central to the micro and meso levels of organisation.	In addition to describing a system using the micro and meso components at this level an epistemological element is introduced enabling the system to be researched in an ecotechnological (Chapter 2, Section 2.1) way. In this thesis this is achieved by mapping principle classification systems to produce a novel epistemological tool to investigate function in 'natural' systems

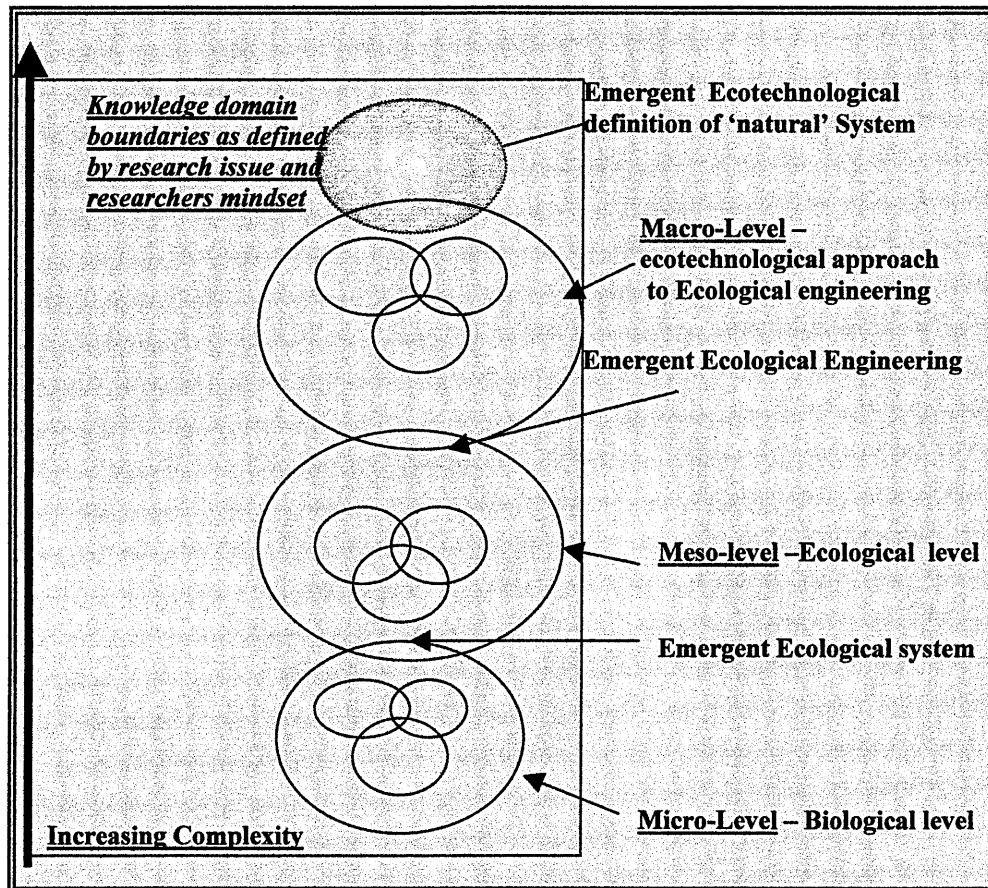
1.2.4 Emergence

The following diagram (Fig 1.4) endeavours to represent the vertical mapping of the 'micro', 'meso' and 'macro' levels listed in the above table. Working from the lowest level which in this case encapsulates the physical biological systems which can be

described by the traditional physical and natural disciplines and emerging upwards toward the development of an ecotechnological (Sections 2.1, 10.2) researching approach.

Fig 1.4 Knowledge Emergence from a 'Bottom-Up' Researching Approach

(Emergence diagram format after Hadfield and Seaton, 1999)



1.3 Researching 'natural' Systems: The Ecological Engineering of Wastewater Treatment

1.3.1 Overview

This research investigates a system of wastewater treatment whereby human effects are incorporated into 'Natural' aquatic systems thus rendering them 'natural' and the way in which the 'nature' of such a system i.e. the aquatic flora and fauna responds to, and in turn, effects the system as a whole. This is done by investigating the developing discipline of ecological engineering (Section 2.1) which attempts to understand the interrelationship between humans and Nature and by looking at models and case studies of aquaculture systems .

1.3.2 Water Treatment: Traditionally Designed and Undesigned

The effectiveness of 'natural systems' such as reed beds* and treatment lagoons* for treating wastewater is well documented e.g. Kadlec and Knight, 1996, Metcalf and Eddy, 1991, Mitsch and Jorgensen 1989. Such systems can offer tertiary* (advanced) water treatment in that, via their plant (autotrophic*) component they can substantially reduce effluent nutrient (nitrogen and phosphate) levels and thus act as buffers to prevent eutrophication* in natural water courses.

Water treatment works (termed chemical and biological despite their employment of microbial ecologies) are now also designed around such advanced treatment, their effluent having to conform to an ammonia consent level. Traditionally such wastewater facilities were simply designed around the reduction of two other wastewater parameters namely Suspended* (settleable) Solids (SS)* and Biochemical Oxygen Demand (BOD)*. These two parameters are still used to define the consent criteria of treatment (their reduction being particularly pertinent to primary* and secondary* treatment processes) and are interrelated via changing oxygen levels with the processes of tertiary treatment (denitrification*, nitrification*). As with nutrient loading undesigned 'natural' water courses and wetlands are still often the recipients of SS and BOD which is also referred to as 'organic loading'

1.3.3 Treatment Parameters Used in this Research

This research investigates water treatment processes at various levels i.e. biochemical, biological and ecological. The complexity involved in such multi-leveled research means that it is restricted to looking at 'organic loading' by concentrating on the traditional treatment parameters of SS and BOD.

These parameters are central components of the research and so require defining :

- ◆ Suspended Solids (SS) are in this research, as with stream-pollution-control work, considered as Settleable Solids (SS) because time is not a limiting factor. SS can be described as the amount of matter suspended in sewage that will at some point settle via processes of biological and chemical flocculation.
- ◆ Biochemical Oxygen demand (BOD) refers to the amount of oxygen required by the activities of aerobic* bacteria and other micro-organisms to mineralize* (break down) organic waste. The level of BOD is affected by the level of organic matter and thus suspended solids entering the system.

1.4 A Brief Recapitulation

This research uses as a context the substantive issue of the organic loading by wastewater of aquatic systems. It demonstrates that the way in which the 'natural' components of such systems are classified effects the way in which a system can be viewed in biological, ecological, ecological engineering and ecotechnological terms. Viewing such issue-based research in ecotechnological terms is found to require a 'soft'

(Section 2.1) technological approach defining “*technology as applied knowledge*” (Seaton, 2000). It also requires a re-assessment of the concept of ‘natural’ systems.

Themes incorporated in the substantive research include the idea of interdisciplinarity within science and its facilitation via mapping taxonomies from separate sub-disciplines. This can contribute, in soft technological terms, as *technos* the “*application of knowledge*” and shows that traditional biological classification systems such as the Linnaean taxonomic system (detailed in Chapter 6) are not equipped to deal with the concept of emergence.

1.5 Research Objectives

The following primary research objective was the result of adapting numerous predecessors, detailed in the ‘Research Design Process’, Chapter 5.

1. To explore an ecotechnological, interdisciplinary approach to studying ‘natural’, in ecologically engineered terms, systems.

This objective was approached using a “bottom up” approach to mapping between the taxonomic systems describing the relevant hierarchical levels detailed in Section 5.2.7. It is realized that such an approach reflects the researcher’s mindset which was originally fixed firmly within the biological sciences. Figure 1.5 on the next page illustrates the spiraling relationship between the knowledge domains relevant to representing the hierarchical organization, which dictates ecological change within social systems. Depending upon the researchers perspective i.e. whether there is a bias toward the science or social science disciplines this research spiral can be viewed as a “bottom up” or as a “top down” approach to mapping between the disciplines which constitute the actual structure of hierarchical classification.

The primary research objective can then be resolved into a second, lower level, research objective:

2.To develop an assessment method for investigating the bi-directionality between water quality (biochemical) and ecological change as a socially directed biophysical* or ‘natural’ technology.

The term bi-directionality requires defining, as it is a recurrent one in this thesis. In this context it simply refers to the relationship between the biochemistry of the system i.e. the relevant water quality defined by specific biochemical (wastewater) parameters (Section 1.3.3) and the systems organization of flora and fauna (ecology / biocoenosis*). This relationship is bi-directional in that changing the biochemistry of the system will change the ecology of that system but there is a feedback loop whereby changing the ecology will in turn effect the systems biochemistry. This feedback loop has been enhanced in traditional treatment works where the space in which ecologies (principally microbial ones comprised of bacteria species) operate and the level of substrate (pollution/ biochemistry) upon which they operate is concentrated. In natural water courses and systems such as wetlands and waste-fed aquaculture systems

(Chapter 3) the same bi-directionality still exists but at a macrobial as well as a microbial level and due to the size of the system is, generally, of a more subtle nature. The second research objective led to the development of a third and final objective:

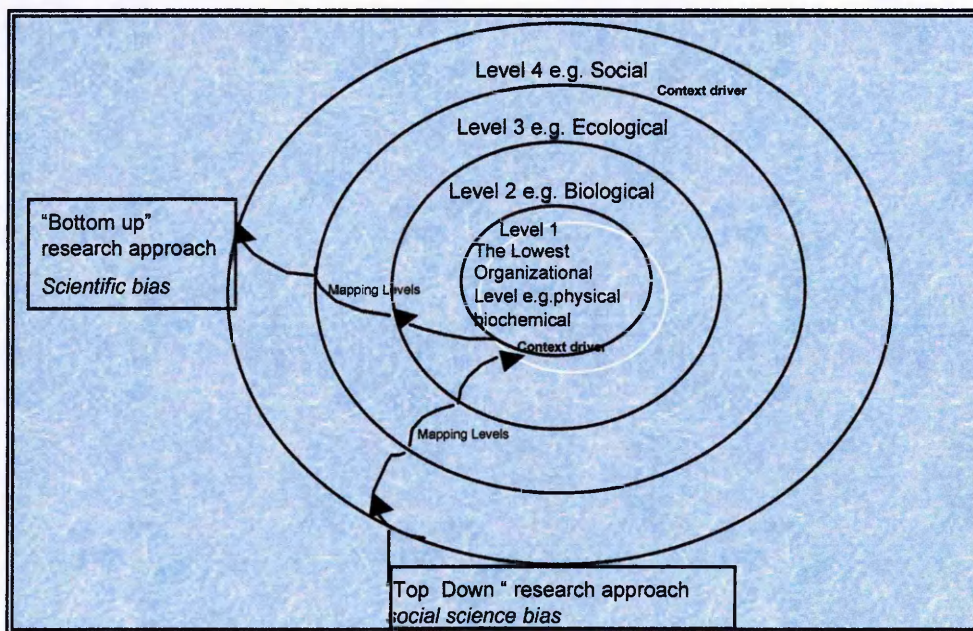
3. To develop a taxonomic framework (ecotaxonomy) which takes into account the concept of emergence in describing such 'natural' systems to allow for objective (interdisciplinary) classificatory adaptation according to the research focus.

This third research objective results in the following main research activities:

- ◆ The application of the taxonomic framework 'ecotaxonomy' to a waste-water fed aquaculture case study.
- ◆ The investigation of the patterns that arise from such a reclassification activity

In addition several interesting side issues are observed with respect to taxonomic manipulation and its role in interdisciplinary knowledge facilitation. (Sections 1.2, 2.4, 10.2). The effect changing categories can have on concepts such as variety and diversity and subsequently on the perception of resilience and stability in natural systems is also investigated later in the thesis (Sections 4.3.3 iii and 10.6).

*Fig.1.5 The Spiraling Relationship Between knowledge Domains Relevant to a Socially Directed Biophysical System**



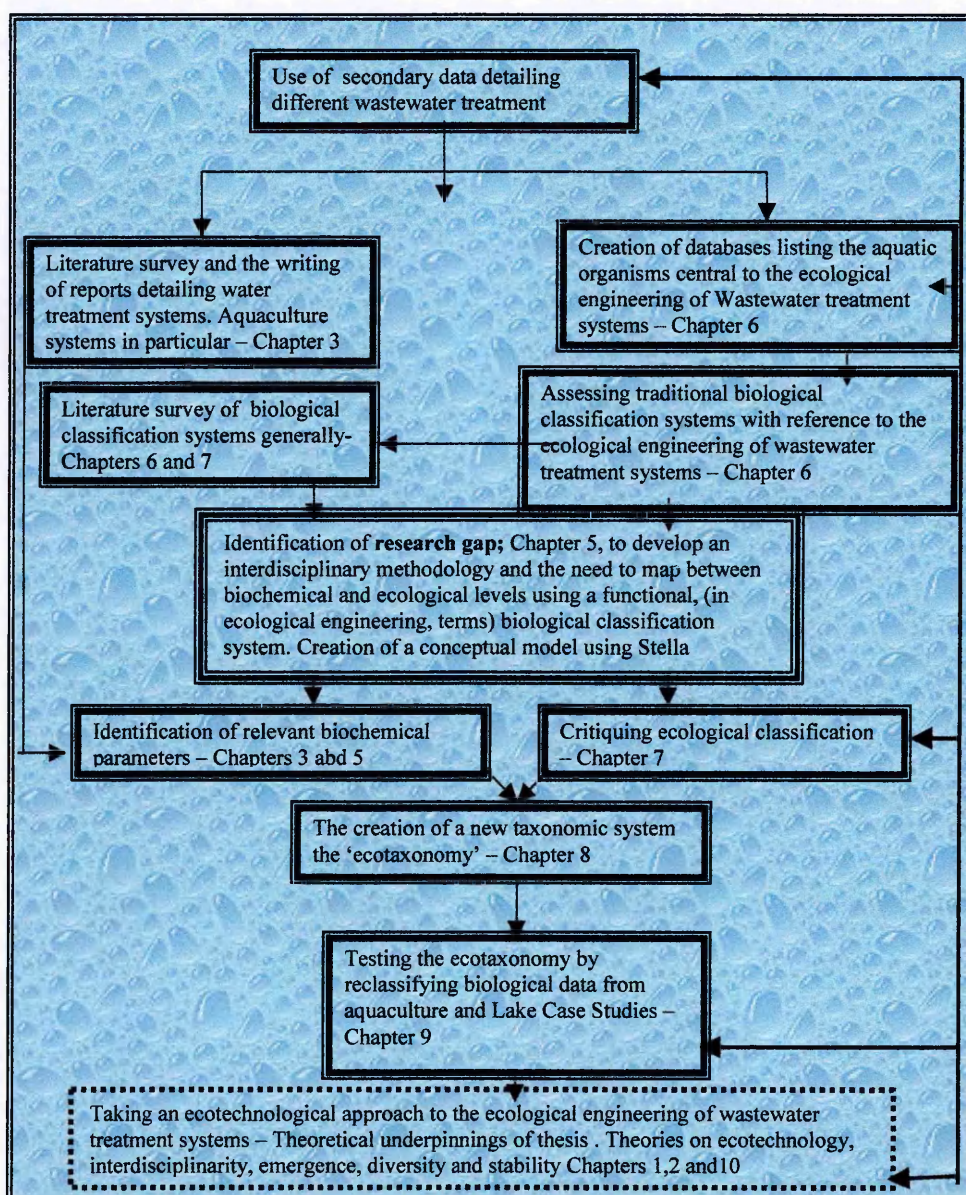
The spiral configuration in Figure 1.5 is used to show that there is no definite delineation between organizational levels. They are in effect nested in one another. As the complexity in each level increases it reaches a point where it can be classed as the next, higher level e.g. from biochemical to cellular state, from biological to ecological and from ecological to sociological where the latter includes (as the world generally does) aspects of human activity.

In this particular context the research driver from a scientific perspective i.e. one using a “bottom up” approach will be the biochemistry of the system, in this case water quality. If the research bias was towards the social sciences a “top down” approach would be taken where the context driver would be located within social science aspects e.g. human need or appreciation of quality/treatment. These ‘organizational’ levels are detailed in table 5.4 are further developed in the conceptual model of chapter 5.

1.6 Thesis Outline

Fig 1.6 illustrates this thesis outline showing the interconnections between the major themes and the chapters in which they predominate. The research activities are overviewed in Table 1.4

Fig 1.6 Research Plan



During the initial stages of research reports were drawn up detailing the processes and biochemical activity central to changing water qualities within different aquatic systems and models of them. Systems within, and external to, recognised water treatment works were investigated these included; wastewater-fed aquaculture systems, lagoon (algal and natural) systems, ponding systems, natural ponds, macrophyte beds, trickle filter systems and activated sludge systems.

The flora and fauna, which comprised such systems, was, where possible, investigated. There appeared to be no clear classificatory framework for categorising and understanding the ecological engineering functionality of the organisms present in treatment systems. This led to the research activities detailed in the following table, these can be related to the 'Research Plan' of the thesis illustrated in Figure 1.6 and to the 'Research Design Process' detailed in Chapter 5.

Table 1.4 Research Activities

<u>Research Activity</u>	<u>Research Details</u>	<u>Thesis Reference</u>	<u>Appendix Reference</u>
Classification of Freshwater organisms	Classifying common freshwater organisms using the Linnaean taxonomic system	Chapter 6 (Section 6.5.1)	<u>Table 1</u>
Classification of Protozoa	Classification of protozoa found in traditional treatment processes using the Linnaean taxonomic system	Chapter 6 (Section 6.5.1)	<u>Table 2</u>
Classification of bioindicator organisms	Classification of organisms using the saprobic index which is relevant to changing BOD levels	Chapter 6 (Section 6.5.4)	<u>Table 3</u>
Classification of commonly aquacultured organisms	Classification of organisms detailing their geographical location and culture potential.	Chapter 3 (Section 3.2.4)	<u>Table 4</u>
Defining different life-stages of Linnaean species	The differing food (consumption) dynamics between life stages of species	Chapter 6 (section 6.5.2)	<u>Table 5</u>
Creation of a 'Binary Matrix' of consumption	Plots a total of 88 organisms against one another to give an idea of trophic types	Chapter 7 (Section 7.4)	<u>Table 6</u>
Creation of a new taxonomic system, the 'ecotaxonomy'	Redefining in excess of 60 ecotypes	(Chapters 8 and 9) (Table 8.5)	<u>N/A</u>
Reclassification of more than 200 aquatic organisms.	Reclassification of biological data using the ecotaxonomy from the Hungarian Case study 1971	(Chapters 8 and 9) (Section 9.5)	<u>Table 7</u>
Reclassification of more than 220 aquatic organisms	Reclassification of biological data using the ecotaxonomy from the Hungarian Case study 1972	(Chapters 8 and 9 (Section 9.5)	<u>Table 8</u>
Reclassification of over 170 aquatic organisms	Reclassification using the ecotaxonomy of biological data from the Little Rock Case Study	Chapter 9 (Section 9.5)	<u>Table 9</u>

The following is an outline of the subsequent thesis chapters:

- ◆ **Chapter Two** explores the mapping and classificatory problems intrinsic to taking an interdisciplinary, ecotechnological approach to research. It does this by exploring the purpose of ecological engineering and the nature of sub-disciplines and classification within the biological sciences.
- ◆ **Chapter Three** describes the ecological engineering of wastewater treatment. It details the processes general to sewage cycling and its breakdown. The key water quality parameters used in the research are identified alongside a rationale for the choice
- ◆ **Chapter Four** cites wastewater-fed aquaculture systems as a central ecological engineering model for exploring the role of interdisciplinarity within the biological sciences in order to approach researching 'natural' ecologically engineered systems from an ecotechnological perspective.
- ◆ **Chapter Five** details the Research Design process and the interplay between the substantive and epistemological objectives of the work. Principle Research Gaps are highlighted. The chapter includes both design and methodological decision rationales. The development of the research objectives and a conceptual model uniting key aspects is described and related to the rest of the thesis.
- ◆ **Chapter Six** concentrates purely on investigating the complexities of biological classification, particularly the 'Linnaean' taxonomy. It highlights the strengths and weaknesses of using such a taxonomic system in the context of ecologically engineered systems.
- ◆ **Chapter Seven** investigates ecological complexity. It concentrates mainly on the use of trophic levels to define/classify functional types by merit of interaction. It illustrates how patterns of consumption within an aquatic ecology are a dominant force in directing water quality change i.e. are central to the elusive 'self-purification capacity' of 'natural' water systems.
- ◆ **Chapter Eight** examines the design of an 'ecotaxonomy' which is an 'inter' taxonomic system for defining aquatic organisms as functional types within a defined water quality change system. The 'ecotaxonomy' is actually a new, context driven, biological classification system, which unites aspects of previous biological, and ecological classification. In doing this it also enables a level of mapping between the different sub-disciplines describing the system.
- ◆ **Chapter Nine** concludes the methodological section. It shows the interaction of the abstract model and the ideas developed from it using secondary data from both a 'natural' and a relevant 'ecologically engineered' system. The former is a lake food web and the latter is an aquaculture case study. The

analysis of these studies is used as a platform to study hypotheses concerning the taxonomic developments detailed in the previous chapter.

- ◆ **Chapter Ten** concludes the intellectual aspects by relating the research findings to the perceived theoretical underpinnings. It iterates the main themes of the thesis and it's contribution to knowledge. It defines not only, the limitations of this research but also highlights its wider implications and utility.

Chapter 2.

Ecological Engineering: An Interdisciplinary (Ecotechnological) Approach

2.1 Introduction

Ecological engineering can be defined as

“the design of human society within its natural environment for the benefit of both” (Mitsch and Jorgensen 1988).

The purpose of ecological engineering

“to learn to establish a mutualistic relation with ecosystems, using the resources of General System’s Theory” (Ortega et al 1997 [http¹](http://))

somewhat tightens this definition but still relies on the notion of ‘ecosystems’ which are notoriously difficult to delineate objectively (see Section 7.1) as systems pertinent to such issue-driven research.

Ecological engineering is frequently referred to as ecotechnology (or eco-technology)

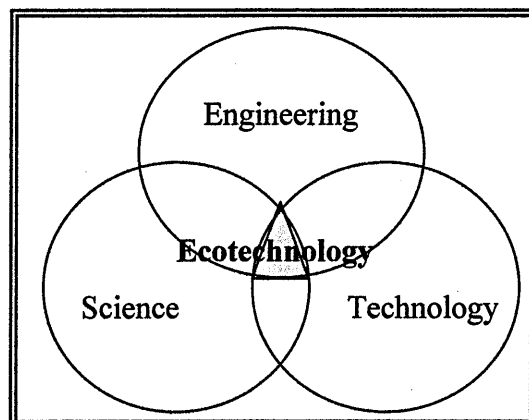
“ecological engineering aka ecotechnology” (Mitsch and Jorgensen 1988).

This thesis shows that ecological engineering and ecotechnology are not one and the same thing although the former can be approached in an ecotechnological manner but only when technology is redefined to include the application of knowledge,

“technology as the study of technos” (Seaton 1997).

Ecotechnology can be seen to arise from the whole engineering-science-technology (“soft” and “hard”) triangle unlike ecological engineering, which possesses only the engineering and science sides of the relationships united as a hard technological approach.

Fig 2.1 Ecotechnology



In Figure 2.1 ecotechnology emerges from the interaction of science, engineering and technology (hard and soft) as opposed to the hard technology of ecological engineering, which emerges from the interaction simply of science, and hard/ structural engineering (as opposed to the engineering of social , knowledge transfer systems/ organizations).

Ecological engineering looks at the way physical systems can be designed to incorporate 'natural' processes and this is referred to as a 'hard' technological (ecotechnological) approach. To do this requires using knowledge bases from both the natural and physical sciences, this is different from using each of them exclusively and requires a new interdisciplinary method of investigation. This use or 'application of knowledge' itself forms a 'soft' technological approach or ecotechnological approach to the ecological engineering of systems.

In this chapter the ecological engineering and ecotechnology of wastewater treatment systems are related to general mapping and classification problems intrinsic to any interdisciplinary research agenda. This can be done by:

- ◆ Taking a historical perspective to investigate the changing definitions of technology, the development/divergence of scientific disciplines and then the subsequent re-emergence of interdisciplinarity and by briefly reviewing ideas on nature and holism including General Systems Theory (Von Bertalanffy 1962).
- ◆ Referring to other ecotechnology research projects which have encountered similar difficulties when faced with the need to map between disciplines.
- ◆ Considering the problems encountered when attempting to use an integrative, interdisciplinary approach to researching within the biological sciences.

2.2 Science, Technology and Technoscience

2.2.1 The Great Science and Technology Divide

The term 'technology' evolved from the Greek 'tekhne' meaning art or skill. Technology is now a complex conceptual term which can be related to the practical application of science to industry, the methods practiced and governing this application and the total knowledge and skills available (Grint and Woolgar 1997).

It is helpful to divide "technology" into two types; "hard" technology relating to "non-human" (although human created) elements and "soft" technology" relating to "human elements" such as knowledge bases etc. A comprehensive review of this conceptual term is beyond the scope of this work but it needs to be noted that this thesis uses a "soft" technological element in the form of "*applied knowledge*" (Seaton, 1997).

The traditional divide between science and 'hard' technology can be defined in the following way,

“Science is concerned with knowledge and with understanding the nature of human beings to their environment, whereas technology is concerned with making and doing things, that is, with the way in which human beings change their environment” (Buchanan 1992).

It has long been recognized that there is an ongoing co-evolution between scientific and technological advancement but they are still often viewed as separate.

“The growth of technological activity in the modern world has closely paralleled the development of science, but it is necessary to recognize these as two distinct though related phenomena” (Buchanan 1992)

Table 2.1 A Simple Classification of ‘Science and Technology’

Technology	Science
Concerned with humans making and doing things	Concerned with systematic understanding of humans in their environment
As ancient as the manipulative powers of humans	Only as ancient as literate civilization

NB. This divide could be traditionally related to ideas of social status with science being generally regarded as the province of the literate classes and technology being associated with labourers, artisans and craftsmen. When it became possible to ‘design’ on paper using mathematics etc., progress was no longer limited to actually making an innovation instead it was possible to ‘conceptualize’ and experiment on paper with numbers etc, and produce plans.

2.2.2 Toward Technoscience

The combining of science and technology has produced, and continues, to produce synergistic technological advancement. The development of the steam engine is a classic example which in Baconian terms increased mans ‘dominion over nature’.

During the 18th and 19th century the relationship between science and technology became more symbiotic and as systems complexity increased their mutual dependence became greater. It should be noted here that technology relates to the output of engineering sciences i.e. so called ‘hard’ technology but later it will be seen that when a systemic, interdisciplinary approach is taken the idea of ‘soft’ technology emerges.

“Technology, as the study of technos, thus takes in not only the output of the engineering sciences but also the new forms of organizations which use them, their impacts and interactions with people at large and with the so-called natural systems in which these people are embedded and with which they also interact” (Seaton 1997)

Ecological engineering can be perceived as an example of a technoscience or symbiotic relationship between science, ecology in particular (which includes aspects of all the

other biological sciences) and 'hard' technology concerned with engineering issues related to design, mechanisms and infrastructure.

Other examples of such technoscientific symbiosis include:

- ◆ Biology and biotechnology
- ◆ Chemical science, chemical and biochemical engineering
- ◆ Microbiology and nanotechnology.

2.2.3 The Role of Interdisciplinarity in the Advance of Technoscience

The advance of a technology often requires the input of more than one scientific discipline. That is it will require a multidisciplinary approach. In addition it will require knowledge (technological) transfer between disciplines and in this way will require an interdisciplinary (integrative) approach. The increasing technological dependence upon scientific theory necessitates formalized instruction and knowledge transfer.

By redefining technology as "applied knowledge" old stereotypes used to distinguish between science and technology are actually questioned and soft technology is seen to emerge from interdisciplinarity.

2.3 Scientific Disciplinarity, Nature, GST and Interdisciplinarity

2.3.1 Disciplinarity

There appears to be a close parallel between the developmental history of academic/scientific disciplines and the adoption of technological fix 'ations' which contribute to a certain level of "technological determinism".

For example the evolution of biology (particularly microbiology and biochemistry) as a science and biotechnology reflects the desire of humans to control 'natural' systems creating, via genetic manipulation, new strains of organism which will carry out predetermined (when possible) specific functions. Ecological engineering (as defined in 2.1, not ecotechnology) is on the other hand a comparatively new concept being

"almost at the stage where biotechnology was twenty years ago." (Mitsch and Jorgensen 1989).

Conventional biological water treatment systems, for instance have been designed from the chemists and the biotechnologists perspective and although biotechnological processes are still evolving,

"most researchers and environmental managers now agree that biotechnology will not solve the world's environmental problems and that there may be some adverse consequences from its development" (Mitsch and Jorgensen 1989).

It is not surprising that a biotechnological fixation should supersede an ecological engineering one. It is, after all, much easier to contain and test microbial systems in

vitro in laboratories than it is macro-ecologies although the former will be released to the latter with subsequently unanticipated results.

Specialism generally goes hand-in-hand with reductionist and mechanistic approaches to problem solving and viewing the world. The concept of 'nature' is a central theme in this thesis as ecologically engineered systems are often termed 'natural systems'. The next two sub-sections attempt to show how perspectives on natural systems have changed over time and how the mechanistic and holistic view of nature differ.

2.3.2 A Holistic View of Nature

In recent decades, particularly from the 1950's the emergence of systems research concepts (von Bertalanffy, 1951, Checkland, 1976) has started to override the mechanistic, reductionist approaches popularised in the C17th.

"The tendency to study systems as an entity rather than a conglomeration of parts is consistent with the tendency in contemporary science no longer to isolate phenomena in narrowly confined contexts, but rather to open interactions for examination and to examine larger slices of nature" (Von Bertalanffy 1962).

Ludwig von Bertalanffy first presented his "General Systems Theory" in 1937 in Charles Morris' philosophy seminar in the University of Chicago. During this time biology was involved in the mechanism-vitalism debate the former being preoccupied with a reductionist, mechanistic view of living organisms as accumulations/sums of their constituent parts. This theory paradoxically required the vitalism theory to account for the problems of self-organization

"soul like factors, like hobgoblins" (Von Bertalanffy 1962).

"General Systems Theory" was born, via the advocacy of an 'organismic viewpoint', the study of open systems and steady states which is essentially an expansion of conventional physical chemistry, kinetics, thermodynamics and further generalization. It is at this point useful to delineate between three major theories on life and nature, which have emerged over time.

Table 2.2 found on the following page, lists these three theories on life and the nature of it giving a brief description of each. Each of these theories is the result of differing academic interjection by a mixture of the scientific i.e. natural and physical disciplines or various mixtures of them. The latest theory incorporates the idea hierarchy or nested levels in systems and attempts were made during this time to relate the different hierarchical levels of living (animate) organizations; atoms, organisms, planets etc. to the discipline which describe them. Later in this Chapter Fig. 2.3 shows a different scenario i.e. how one hierarchical level of living/animate organization, i.e. the organism, can be defined by and in relation to numerous different scientific disciplines and sub-disciplines. This also relates back to Section 1.2 of the last chapter.

Table 2.2 Three Major Theories on Life and Nature

<u>Theory of Vitalism</u>	<u>Mechanistic Theory</u>	<u>Holistic,Organismic/ Organicismic Systems Theory</u>
Dates back to the C 17 th and maintains that living organisms are truly alive, animate rather than inanimate. It is a development of the animistic theory of nature which was dominant in Europe before the mechanistic revolution. Whereas the old animistic theories treated all nature as alive to some degree vitalism confined life to biological organisms. This explains the purposiveness of living organisms in terms of their souls or life-principles.	Dates back to the C 17 th Denies that there is any difference between living organisms and dead organisms or inanimate matter in general. It regards organisms as inanimate machines. Although when organisms die their organization breaks down, there is no difference in kind between a living and dead organism – life does not involve any additional principles unknown to physics – but only a difference of degree. The organization of living organisms somehow emerges from complex physico-chemical interactions in a manner that remains an obscure problem for mechanists. The soul has to be reinvented in a mechanistic guise. During the late C 19 th the inner organizing principle was identified as the “germ plasma” inside the cell nuclei and has now been attributed to molecules of DNA i.e. genes. But far from being inanimate molecules these genes have been endowed with all the properties of life and man- they are even supposed to be selfish (Dawkins, 1976).	Developed since the 1920’s this holistic approach attempts to transcend the vitalist-mechanist argument. It agrees with the mechanists in affirming the unity of nature, seeing the life of organisms as different in degree from the rest of the physical world, but not different in kind. But it agrees with vitalists in stressing that organisms are organic wholes, and cannot be reduced to the physics and chemistry of simpler systems. They are an ‘emergent’ property of the simpler systems which comprise them. The holistic theory in effect treats all nature as alive and in this respect represents an updated version of pre-mechanistic animism. Here even crystals, molecules and atoms are organisms. They are not made up of inert atoms of matter as is cited in atomism. Modern physics have shown they can be considered structures of activity, patterns of energetic activity within fields.
<u>Disciplinarity/Interdisciplinarity</u>		
<u>Theory of Vitalism</u>	<u>Mechanistic Theory</u>	<u>Holistic,Organismic/ Organicismic Systems Theory</u>
Disciplinarity-Life is left to biologists whilst the rest of nature is left to mechanistic physics	Disciplinarity - As organisms are regarded as inanimate machines they are thought to be governed by general laws of nature, which apply in the realms of physics and chemistry. Although many modern biologists claim to be mechanists in effect the paradigm of modern biology has become a cryptic form of vitalism in which genetic programs’ or ‘selfish genes (or memes on a higher organizational level) play the role of ‘vital organizing factors.	Interdisciplinarity-In the words of Alfred North Whitehead “Biology is the study of the larger organisms, whereas physics is the study of the smaller organisms” in the light of modern cosmology physics is also the study of the mega all embracing cosmic organism and of the galactic, stellar and planetary organisms evolving within it. This relates to the idea of hierarchy in systems and the disciplines describing each hierarchical level.

2.4 Interdisciplinarity

By the mid 20th century in Western society there arose an urgent need for integration especially in those scientific circles where general philosophical principles were not accepted as interpretative frameworks of scientific findings.

“A number of scientists are now turning to “integrative concepts” in the response for the need of general theories which interlink atomistic specialties on very basic conceptual grounds and assure contact between them as well as the emergence of a coherent world-picture” (Laslo and Margenau 1971).

Defining interdisciplinarity is difficult despite it being a concept of wide appeal. Methods of restructuring knowledge by integrating between disciplines to create unified or holistic perspectives can be termed interdisciplinarity.

Interdisciplinarity can be used for a range of objectives (Thompson Klein 1990)

- ◆ To answer complex questions
- ◆ To address broad issues
- ◆ To explore disciplinary and professional relations
- ◆ To solve problems that are beyond the scope of any one discipline
- ◆ To achieve unity of knowledge, whether on a limited or a grand scale.

The substantive research presented in this thesis is made up of a rather *narrow* form of interdisciplinarity. This seeming paradox actually relates to the issue of ‘simplification’ in that all systems thinking is in a sense ‘reductionist’ but the rules of reduction are different from those of Cartesian logic and are dependant on the system of interest. It is important prior to this ‘simplification’ to capture the holistic aspects which require defining. This research does this by a series of classificatory activities (Chapters 8 and 9)

“Interdisciplinary may be used to describe converging theories among parts of the discipline familiar to the researcher e.g. the physicist may take elements from modern physics, biology and chemistry whilst remaining unaware of its role in social sciences.” (Thompson Klein 1990)

In this thesis an attempt is made to integrate the substantive sections (see Chapters 6, 7, 8 and 9) which comprise such *narrow* interdisciplinarity located within the biological sciences, in a framework of wider real interdisciplinarity, by using relevant social science aspects, namely, definitions of ecotechnology, technology as ‘applied knowledge’, and using an innovative epistemological approach to reclassify data.

2.5 Recurrent Problems of Interdisciplinary Research and Discourse

“Moving across disciplinary and intellectual boundaries is often difficult and frustrating, even within a small group of highly motivated friends” (Winder 1997).

The role of vocabulary when attempting to integrate knowledge from different intellectual domains cannot be overstated.

“Science and scientists driven by the need to distinguish, define and describe, are infamous for developing new vocabularies and even new words. It is not surprising therefore, that when representatives from two different scientific disciplines meet, they have difficulty making themselves understood” (Jeffrey 1997).

The idea that the same phenomenon is often described using different dialect according to specialism is a recurrent theme not only of this thesis (e.g. Section 1.2 and Fig 2.3), but also in many other research projects. For instance it is found to crop up regularly in reports on the Environmental Perception and Policy Making (EPPM) which although an offshoot is (paradoxically) an integral element to the ARCHAEOMEDES projects where interactions between nature, culture, science and policy are common themes. These projects are further detailed in Chapter 10.

“Hence, even though the representatives of different disciplines may be discussing a single, unambiguous topic, the vocabularies they choose to communicate with maybe very different and mutually perplexing.” (Jeffrey 1997).

Useful categorization is dependent upon defining accurately the research context and objectives. For instance biologists tend to be working toward developing, from the original Linnaean taxonomic system (Chapter 6), what they term a ‘natural’ taxonomy which reflects the ‘real’ phylogenetic* relationships between living organisms both extinct and extant to provide a conclusive picture of how the ‘natural’ world has evolved. Such a project requires a multidisciplinary approach between archeologists, palaeontologists, zoologists, microbiologists, geneticists, biochemists, anatomists and many more and the use of molecular mapping, genetic sequencing, cladistics* and other techniques. In such an evolutionary scheme man is classified as simply another extant species but clearly the role of *Homo sapiens* as part of and in shaping nature and as the classifier of nature is what has led to our perceived separation from nature. In this way “natural” biological classification is, from an anthropocentric perspective, ‘unnatural’.

“However natural categories are, we need to search whether and by what means they find their existence as natural categories” (Coupland 1988).

Biologists may be using the evolution of the world as their central objective for creating a classificatory system but issue driven or policy relevant research does not generally stem from such ambition and always has to be carried out with the rather depressing axiom that ‘optimal solutions do not exist’.

“Knowledge can only be usefully applied (that is technology as applied knowledge only works) within a particular context” (Jeffrey 1997).

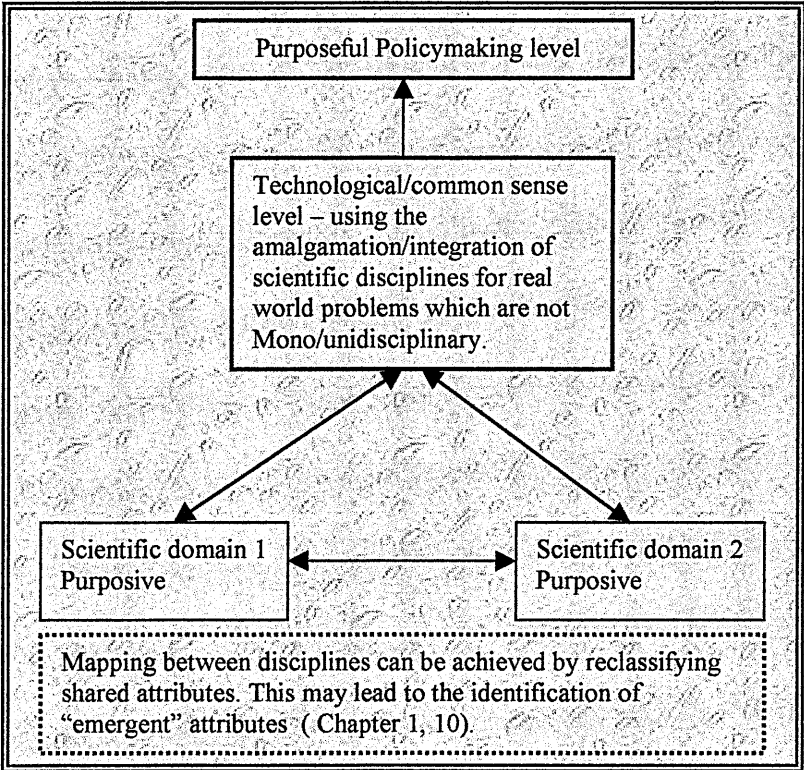
Interdisciplinary research therefore always requires the setting up of clear objectives for knowledge application. In this thesis the context is organically loaded waters and the description of the biological dynamics which change water quality. The objective is to map between the biochemistry and the ecology defining the “self-purification” system (Section 3.1). This should enable a fuller appreciation of how the variety of organisms, as biological expressions within a system, contribute, via an element of their functional

diversity (which incorporates their ecological interactions), to its self-cleansing potential. Therefore the taxonomic structures produced in the context of this thesis will not be the same as those produced by a biologist wishing to classify the evolution of the ‘natural’ world or their perception of it (Table 10.2).

In general terms interdisciplinary research can be used for a common problem-solving purpose. There is a tendency to think of the mapping between disciplines as occurring in a horizontal non-hierarchical fashion. When the vertical coordination of disciplines is added to the interdisciplinarity equation then the result is often termed “*transdisciplinarity*” (Thompson Klein, 1990). It is therefore very tempting to imagine that there is some linear progression from ‘disciplinarity’ through ‘multidisciplinarity’ through ‘interdisciplinarity’ to ‘transdisciplinarity’ (not to mention paratransdisciplinarity) but this detracts from the idea that any form of disciplinarity is simply a tool for learning, understanding and communicating.

The following diagram (Fig. 2.2) positions the mapping, integrative (interdisciplinary) level of this research within the broader context of policy relevant issue driven research. It serves to illustrate that a bottom-up approach is being taken, note the unidirectional arrow to the highest purposive policymaking level, this allows for ideas of emergence (Chapters 1 and 10) but is restrictive in that it loses out on early realization of the bigger social picture that a top-down research approach would have provided.

Fig 2.2 Taking a ‘Bottom-Up’ Approach to Integrative Research (see also Chapter 1)



It should be noted that the term ‘purposive’ applies to the distinction made by Ackoff whereby human “systems” or individuals can change and choose ‘objectives’ as

opposed to physical/biological systems which, it appears, cannot choose or formulate in such a way.

“Whereas both (he is referring to organizations and organisms) are purposeful systems organisms do not contain purposeful elements. The elements of an organism maybe state-maintaining (homeostatic), multi-goal-seeking or purposive; but not purposeful” (Ackoff, 1976)

The shared phenomenon and/or it's shared attributes (Section 1.2.1, Fig 2.3) when described by separate disciplines which capture the key differences between the systems interacting components (biological units/individuals in the case of ecologically engineered systems)

“should be captured by the rules of the new taxonomy” (Allen 1998).

These rules will depend upon the time scale the taxonomy is designed to reflect. For human engineering of ‘natural’ systems this time scale will be magnitudes shorter than that used for evolutionary/phylogenetic biological classification simply because the former taxonomy will be constantly subjected to changing agendas and classificatory objectives.

In this way, this research into the ecological engineering of water treatment systems has certain similarities with other research projects where there is an overlap between so-called ‘Natural systems’ (Chapter 1) and cultural systems.

Hadfield's thesis (1997) see also (Hadfield and Seaton, 1999) on *“emergent techno-environmental phenomena”* also required an investigation into changes within physical systems and changes in human knowledge or the epistemology of these systems (Fig. 1.4). She however reaches beyond these epistemological levels to look at how changes in human perceptions (*“perceptual emergence”*) actually influence the whole evolutionary complex system.

Other projects, which look at approaches to farming as resource and waste production systems also, encounter problems requiring the mapping across disciplines both vertically and horizontally. Julian Park's thesis (1993) (see also Section 1.2.3) assesses silvoarable agroforestry as an innovative cropping practice within the broader context of developing concepts of sustainability*. In this work he maps not only horizontally across ideas from socio-economic and scientific theory using concepts of sustainability but also laterally across soil/farming systems and ecological systems using agroecosystem processes and then across farming agendas to soil biological systems using farmer's decision making. He also maps vertically through all these mapping functions. He does this by using concepts of socio-economic viability and desirability of change in sustainability terms to link general sustainability concepts and policy relevant information about future farming systems.

Eileen O'Rourke (1995) addressed the idea of *“reductionist epistemology”* in her thesis and states during her criteria for valid knowledge

“different data on the same phenomenon are gathered according to the focus and theoretical tools used by the researcher” (O’ Rourke, 1995).

She then goes on to discuss reductionism and the scientific method, following this by making clear distinctions between “multidisciplinary”, “interdisciplinary” and “transdisciplinary” research approaches. She states that for transdisciplinary research

“disciplinary considerations are subordinate to the subject matter.” (O’Rourke 1995),

It could be argued though that disciplinary definitions are as real as any other linguistic delineation about systems and therefore cannot be subordinate. The transdisciplinary research approach, therefore necessitates the

“creation of new conceptual frameworks into which specific disciplines will undoubtedly feed, but only when they contribute ideas or techniques that clearly serve the larger purpose” (O’Rourke 1995).

Her objective of understanding the socio-natural complexity of her study region to advance an understanding of land degradation in the area also led her to address issues regarding the dualistic split between nature and culture (the man and nature divide) she uses the idea of “*landscape*” to overcome this.

2.6 Multiple Mindsets, Differences and Similarities in the Biological Sciences

People are often referred to using the term ‘biologist’. This is an ambiguous label as one biologist can be, in terms of their knowledge base, an entirely separate academic ‘species’ to another. The reason for this is due to the numerous academic splits within the biological sciences. For example a biological sciences department may contain the following separate disciplines and subdisciplines although the nomenclature will differ between universities and other research institutes.

Table 2.3 Disciplines and Sub-disciplines in the Biological Sciences

Discipline	Examples of Possible Subdisciplines
Microbiology	Cytology, Mycology, Virology, Bacteriology
Genetics	Molecular, Population, Evolutionary biology
Biochemistry	Biotechnology, Molecular biology ,Endocrinology
Zoology	Vertebrate, Invertebrate, Entomology, Aquatic, Terrestrial
Botany	Plant microbiology, Plant physiology
Marine biology	Fish biology, Marine Invertebrates
Ecology	Freshwater, Terrestrial, Behavioural, Conservation, Population, Community, Ecosystem
Palaeontology	Vertebrate evolution, Invertebrate evolution, Plant evolution
Physiology	Human, Animal (general), Plant

Although there will be some overlap in syllabi each biological discipline will have its own mindset/knowledge domain and integrating between these can often be difficult.

Innovative findings in one biological discipline are not always usefully translated to other areas of biology (and beyond) where the new knowledge would be useful. A classic example of this can be found in Lynn Margulis' *"The Symbiotic Planet: A New Look at Evolution"* published in 1998

"At Berkeley there was absolutely no relationship between members of the department of paleontology, where evolution was studied, and those of the department of genetics, where evolution was barely mentioned. Because I sought an education in all aspects of evolution, paleontology, and genetics that could illuminate the evolutionary history of cells, at first I was shocked by the depth of academic apartheid. Each department seemed oblivious of people and subject matter beyond its borders. Furthermore, since nearly all the bacterial geneticists at the Bacterial-Virus Laboratory (BVL), on the East Side of campus, began their careers as chemists, most were abysmally uninformed about the genetics of plant and animal cells"(Margulis 1998).

Margulis then goes on to explain how the Bacterial-Virus faculty students knew nothing about cytoplasmic inheritance where genetic transference occurs in cell organelles other than the nucleus, a key point in her developing 'endosymbiotic' theory of cellular evolution.

Interestingly Margulis found that problems of ignorance stemmed not only from specialist but also multidisciplined biologists who had entered the biological sciences from a physical science background.

"No bacterial geneticist, microbiologist, or virologist at that end of campus knew anything about genetic systems in the cytoplasm of algae. Some were so bacteriocentric that they barely understood mitosis, the kind of cell division characteristic of cells with nuclei. Certainly they never taught or even thought about the special variation of mitosis, called meiosis, that underlies the rule of Mendelian heredity. Many knew nothing about heredity, which applies only to nucleated organisms. So arrogant were these johnny-come-lately biologists-trained in physics and chemistry- that they did not even know they did not know. Many transmitted chemical sophistication but biological ignorance to their graduate students." (Margulis 1998)

Although she is referring to a time during the 1950's which preceded any notion of integrative biology (more that just the plumbing now connects different classes) this rather lengthy anecdote serves well to illustrate the problems that discipline and knowledge acquisition boundaries pose. It is not enough to be a specialist in a field or to be a multidisciplined 'Jack-of-all-trades-(master of none)'. The secret of useful facilitation of knowledge would appear to come from effective communication channels between disciplines and their departments that is from interdisciplinarity. The interdisciplinary approach to research however is not a simple one and can require several levels of mapping (Section 1.2.2, 10.3).

2.7 Mapping Between and Beyond the Biological Sciences

“The physicist describes knowledge in terms of elements and particles, the mathematician in terms of subsets and vectors, the biologist in terms of symbiotic ideals and fecundity, the economist of market strategies, the anthropologist of disciplinary ethnocentrism and tribal rivalries, the systems theorist of feedback and cybernetic relations, the sociologist of sibling rivalries- and predictably so on” (Thompson Klein 1990)

A key problem to sharing knowledge and its utility between disciplines especially closely related ones such as many of those in biological sciences is that different frameworks, languages and classification/taxonomic systems are often used to describe the same phenomena.

This thesis concentrates on the different ways organisms which are generally a clearly physically delineated organizational level are classified firstly at a biological level and secondly at an ecological level. Although the same organisms are being defined they are done so in completely different ways.

Table 2.4 Comparing Biological and Ecological Classification of Organisms

Biological Classification of Organisms	Ecological Classification of Organisms
Organisms classified as separate entities using the Linnaean taxonomic system	Organisms classified relative to one another using a system of trophic levels

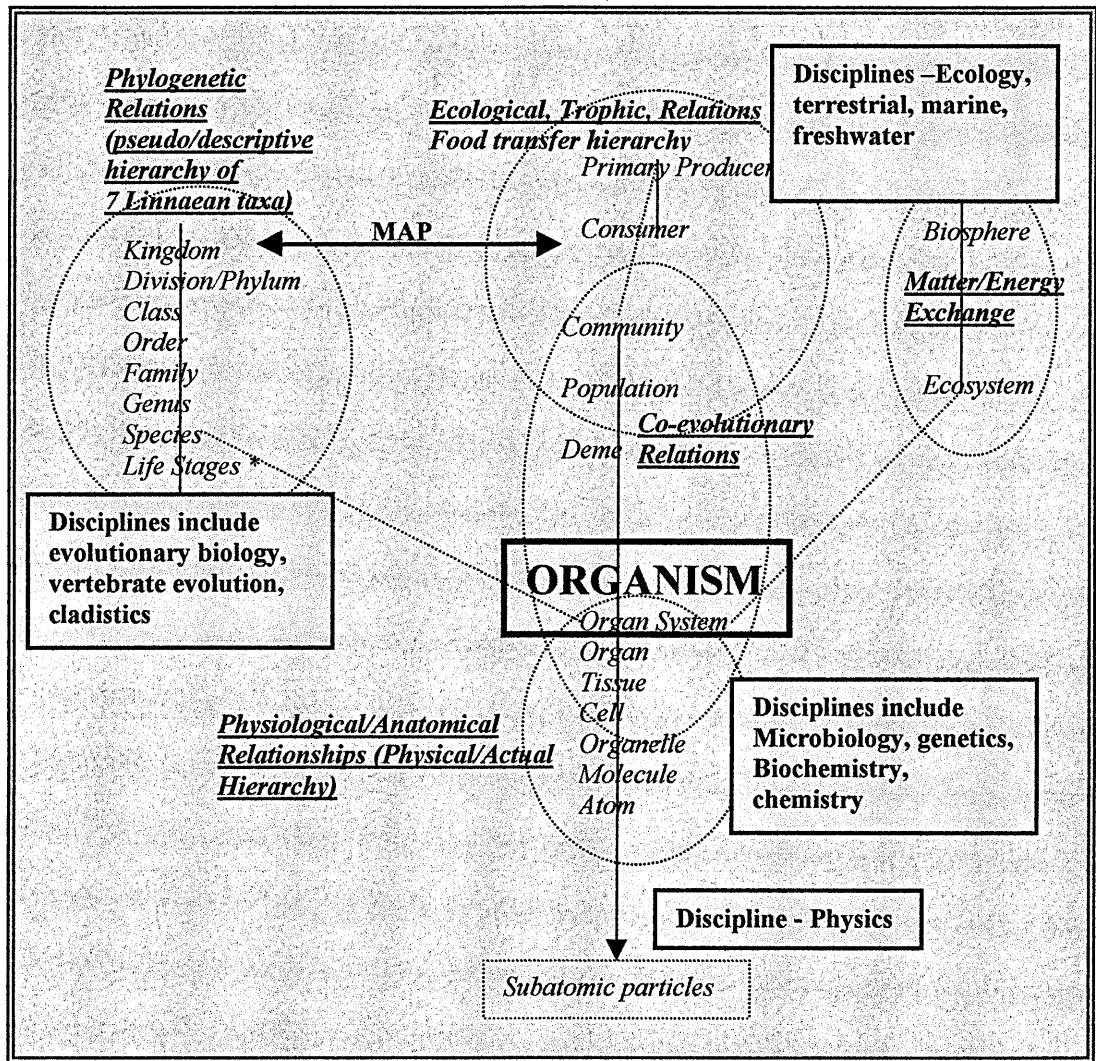
This seems acceptable, as the boundaries of definition and disciplines are made to appear very clear, but in terms of taking a holistic systems approach to issue driven research such divisions and multiplicity become problematic because it could potentially hinder the transfer of knowledge about ecological system especially when non-biologists are the recipients of such duality.

Figure 2.3 locates the organism as a biological unit of organisation within the complex array of hierarchies, real (physical) and those (illustratory), which describe it. The hierarchy used is dependent upon the discipline involved.

The differences between disciplines in biological sciences stems, unsurprisingly, from that factors which differentiate disciplines generally i.e. the system boundary or scale/scope of interest which itself relates to the organisation/hierarchical level being described.

Fig 2.3 Mapping in the Biological Sciences: Relationships of the Organism Relative to Academic Disciplines

(diagram adapted and abridged from MacMahon et. al 1978)



Those disciplines, which are nested within others, will obviously share characteristics. High level (in structural organization terms) biological disciplines such as ecology will contain elements of lower organisational levels for instance biochemistry, genetics, microbiology, animal physiology etc. Lower level disciplines like biochemistry and molecular science genetics appear academically non-dependent on the higher organisational levels (in physical/structural terms) emerging from their microbial organization. In actuality, however, these micro levels are effected by the macro organizational levels but the way discipline frameworks are set up discourages the study of these effects.

The idea of a top-down connectance only comes to the fore when problems, such as the ‘bovine spongiform encephalopathy’ (BSE) scare and doubts in the safety of genetically modified food stuff , reach the social arena and then it is realized that human cultural

practice can create unanticipated microbial outcomes which can then feedback to effect society at many levels. Another relevant example is the global use of antibiotics and the presumed connection to the creation of 'super bugs'.

However a lot of the reported social disasters which result from feedback of this top-down relationship and mutation at microbial levels are as much a result of "*perceptual emergence*" (Hadfield, 1997) and the human propensity toward over-imagination in possession of limited facts.

To sum up, the way in which scientists shape their specialist knowledge base is not always useful in terms of understanding those parts of a system essential to sociological/technological development. The development of scientific disciplines, it needs to be remembered, is itself situated within social agendas of 'protecting one's interest' and so the demarcation between disciplines is not always an objective one in terms of how practically knowledge bases and data are grouped and reflective of processes to contribute to "*information and wisdom*" (Allen, 1994). Also whilst some phenomena are specific to a discipline such as clouds to meteorology and viruses to virology other disciplines appear "greedy" in terms of their subjects. When for instance does molecular biology stop being molecular biology and mutate into another discipline such as biochemistry or colloid science?

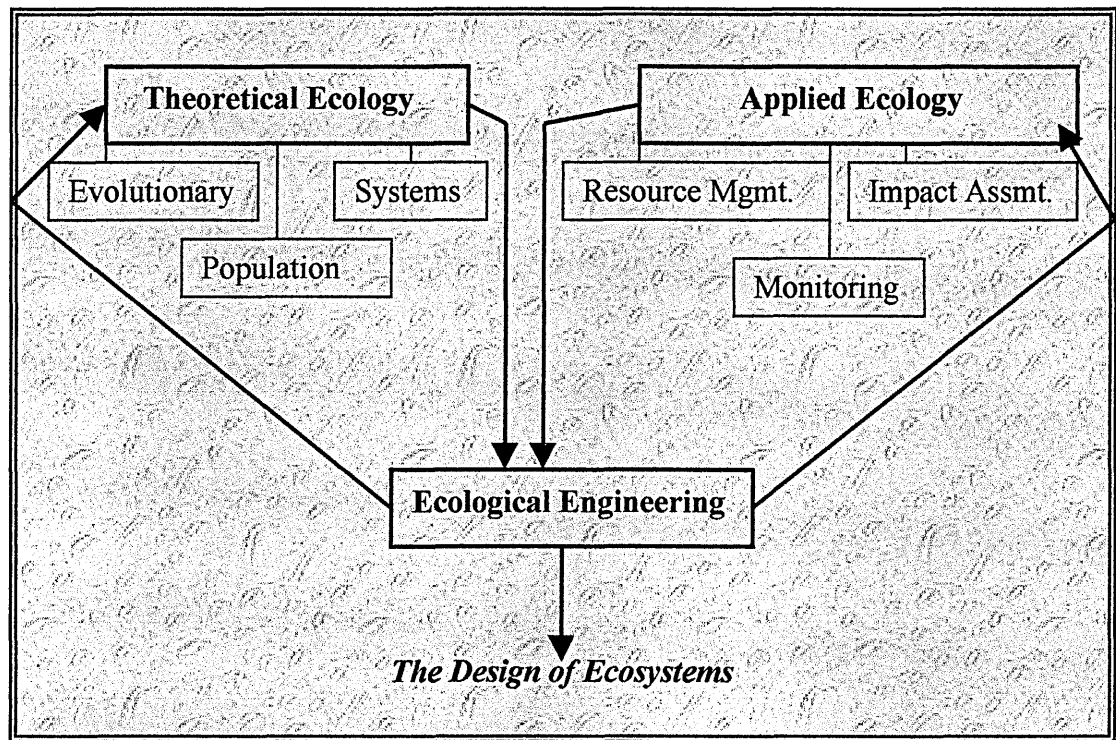
Ecology is particularly fraught with difficulties of scale. Traditionally the ecologist is dehumanizing nature by excluding the actions of *Homo sapiens* and regarding them as somehow unnatural (see Chapter1). In this respect the ecology of systems differs from the idea of ecological engineering although many ecological concepts are central to the development of ecological engineering models. This can be seen from the following diagram. (Fig. 2.4). The feed back arrows from ecological engineering show that it can, in turn, enhance the establishment and testing of basic ecological theories.

"Both theoretical and applied ecology provide fundamentals to ecological engineering but do not define it completely. Ecological engineering, in turn, feeds back ecological theory and management practices to theoretical and applied ecology." (after Mitsch, 1989).

The problem is that the organisms comprising the traditional idea of a natural ecology are not actually separate from environments considered 'man-made'. If the ecological engineering of waste water treatment systems is taken as the central example of this thesis then by taking the different biological disciplines describing or classifying the organisms (biota) of a system and integrating them, a technological (*technos*) level in terms of knowledge application actually emerges. This subsequently means that an ecotechnological approach to ecological engineering is actually investigated. In this way the research shifts away from '*technos* meets *bios*' and toward a redefining of *technos* by applying knowledge of *bios*. Thus the term 'technology' as 'ecotechnology' can be used to describe applied knowledge emerging from the interaction of the different knowledge domains which comprise the biological science knowledge base.

Fig. 2.4 Contributions to Ecological Engineering from the Main Branches of Ecology
(after Mitsch and Jorgensen 1989)

The relationships between the disciplines of theoretical ecology, applied ecology, and ecological engineering.



Abbreviations: *Impact Assmt* – *Impact Assessment*
Resource Mgmt – *Resource management*

The next chapter investigates the ecological engineering of wastewater treatment specifically. Wastewater-fed aquaculture as a central ecological engineering example is then detailed in Chapter 4.

Chapter 3.

Ecological Engineering Water Treatment

3.1 Introduction

Researching ecologically engineered systems for wastewater treatment requires acknowledging ecological interactions as processes within socially directed biophysical/ 'natural' technologies.

Doing this involves the redefining of the term technology (Section 1.2, 2.1, 10.2) to enable the description of interactions, within the biophysical systems essential to society, to be mapped and classified in a way to model the processes, which are integral to the social treatment of water generally.

Central to this research is an assessment of "water treatment" which involves defining the technological potential of the biophysical processes integral to water quality change. The approach taken involves modeling the bi-directional interaction between water quality and ecological change.

This bi-directional relationship represents the frequently referred to 'self-purification capacity' (Guterstam, 1995, Mitsch and Jorgensen, 1988) of aquatic systems. This 'self-purification capacity' of aquatic systems can be defined at a microbial level quite simply

"self purification is the microbial breakdown of complex organic molecules into simple organic molecules together with processes of dilution and sedimentation" (Mason 1996).

Self-purification at an ecological, macrobial level is a more complex phenomenon and requires the inclusion of further ideas of "*self organization*" (Prigogine, 1976, Jantsch, 1983)

"In order to mobilize fully the self-purification of a body of water for sewage treatment, the main principle is to utilize the coordination among four kinds of chief factors in aquatic ecosystems" (Shijun and Jingsong 1989), namely

1. Producers: Algae and aquatic vegetation
2. Consumers: Fish and other aquatic animals
3. Decomposers: Bacteria
4. Abiotic Factors: Solar energy, water and other chemical components

(After Shijun and Jingsong, 1989)

The first three types of factors represent the biological or biotic system components whilst the fourth kind includes non-biological or abiotic parameters.

It is the interaction between the biota and abiota of aquatic systems which is of principle interest when investigating the phenomena of 'self-purification' within a system of water quality change, whether ecologically engineered or not. Investigating such an interrelationship requires an interdisciplinary researching approach, mapping knowledge domains both within the biological sciences and across into the social sciences which allows for the emergence of

"technology as the study of technos" (Seaton, 1997)

The next section details the context of water quality change within which the research operates.

3.2 Defining Sewage and the Cycle of its Breakdown

Domestic sewage can be defined in general terms as

"a mixture of water and various types of organic matter, which we send through plumbing – faeces and urine, food scraps, hair and toilet paper for example. Domestic sewage also contains household chemicals and detergents" (Grant et al,1996)

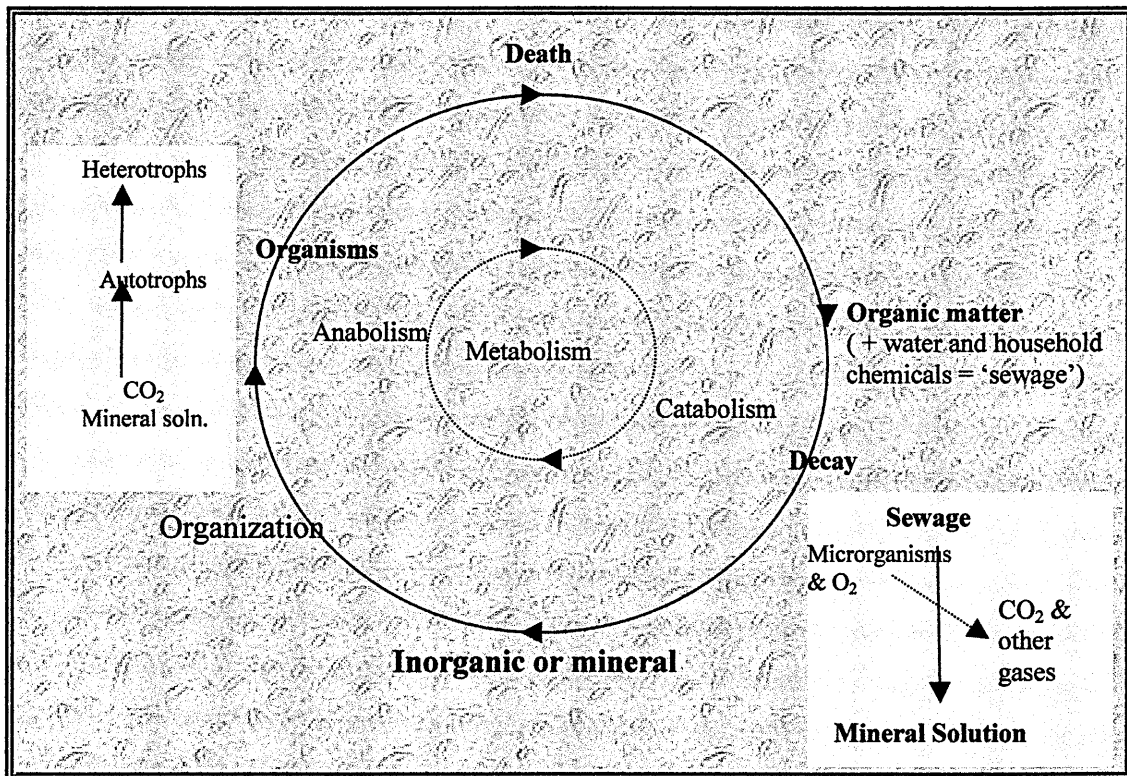
Sewage like all organic matter is subject to 'breakdown' and at all stages of this breakdown some energy is released. This energy can be used by the microorganisms, which facilitate the breakdown process and generate heat. If conditions are right this microbial breakdown will continue until all that is left is a solution of minerals dissolved in water, thus the process of breaking down organic waste is often called 'mineralization'. Confusingly other terms are also used such as digestion, catabolism (see Fig 3.2), disintegration or dissolution. All these refer to the same process of 'breakdown' which is the principle aim of sewage treatment systems.

The need to 'treat' sewage relates to the fact that the micro-organisms which break down sewage are far more efficient at using dissolved oxygen than more highly evolved creatures such as fish which live in relatively unpolluted waters. If untreated sewage is dumped straight into a watercourse aerobic microorganisms will quite simply out compete higher organism in their quest for oxygen meaning that the latter effectively suffocate. In addition sewage contains potentially pathogenic materials and organisms; chemical compounds, bacteria, viruses and worms (e.g nematoda).

The following diagram illustrates the sewage cycle with its catabolic descending semi-circle turning into its anabolic ascending semi-circle. The basic processes, associated with each of these, which comprise this sewage treatment are also detailed.

Fig 3.1 The Big Sewage Cycle

(Adapted from Grant et al 1996)



In addition to a wide variety of microorganisms (Section 6.6) sufficient heat and oxygen are needed to turn sewage into mineral solution efficiently.

After primary treatment it is not so much a case of removal of material from water (although it is possible to remove minerals from solution) but of transformation as, although the greater part of the carbon will exit as carbon dioxide, the mineral solution will contain mostly the same atoms as the sewage did prior to microbial activity.

This transformation cycle is defined as the catabolic side of sewage metabolism the other half is anabolism which describes the multiplication of organisms using simple material substrate (The biochemical submodel of Section 5.2.7).

The environment provided by the stable minerals (unable to be further broken down) provides a medium in which organisms can live, multiply and grow. Initially the organisms suited to this mineralized state are simply microorganisms and plants hence the traditional preoccupation with devising treatment processes which centre around these (trickle filters*, activate sludge systems*, reed beds*, algal ponds* etc.).

A succession of colonization occurs with simple autotrophs (plant life) arriving first which subsequently become food for the arrival of primary consumer heterotrophs* (animal life) and then onto secondary consumer heterotrophs. In this way colonization by phytoplankton through to zooplankton enables the invasion of more complex organisms: micro-invertebrates, larger plants, insects and their larvae, amphibians and

fish. In addition to this, is the colonization of organisms, which inhabit the land around the aquatic system, terrestrial mammals and plants not to mention humans. This organizational half of the sewage cycle is one of anabolism. Death and excretion of the organisms involved generates further fodder for the catabolic limb as the carcasses and other products become integrated into the catabolic cycle.

The stages of catabolism and anabolism are not always discrete. For instance when organisms consume one another the section between Death and Organic matter (sewage) is initially bypassed. The sewage cycles continuously as contaminants in wastewater are transformed, incorporated into living organisms and then regenerated by humans. Presently traditional treatment processes utilize the anabolic side of the sewage circle but only at a micro- ecological level. Wastewater-fed aquaculture on the other hand utilizes anabolic (self-organizing or self-designing) macro-ecological principles.

The fact that decomposing organic matter requires oxygen leads to a convenient way of ascertaining the amount of organic matter present in an aquatic system. The measurement of biochemical oxygen demand (BOD) and suspended solids (SS) (which obscures light even if they do not decompose and reduce oxygen levels) is dealt with in the next section.

3.3 Water Quality Parameters: SS and BOD

Biochemical oxygen demand can be defined as

“the amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions. The term ‘decomposable’ may be interpreted as meaning that the organic matter can serve as food for the bacteria, and energy is derived from its oxidation” (Sawyer et al 1994).

More simply this can be stated as

“the oxygen that micro-organisms require to break down organic matter” (Grant et al 1996)

In this way bacteria are seen to form the initial (trophic) processing unit for the degradation of the sewage. BOD is measured in milligrams of oxygen removed per litre of water over a certain period of time.

The biochemical oxygen demand and the suspended solids define the ‘organic pollution’ of a water body which is related to immediate physical changes in water quality which then facilitate subsequent chemical changes (NH_4 , NO_3 , PO_4), changes in microorganisms and macroinvertebrates (clear graphical representations of these serial changes can be found in Hynes, 1960). In this way the main ‘organic pollutants’ BOD and SS are the catalysts for change at all organizational levels from physicochemical to ecological. It is unsurprising, therefore, that traditional treatment works were designed primarily to reduce these pollutants.

“The regulatory authorities use two main determinants, BOD and SS to set the discharge standards to be achieved by small sewage treatment systems. Many other determinants (nitrogen, phosphorous, sulphur, and pathogens) exist that are considered to be of less importance (at the small scale) with respect to the health of water bodies”. (Grant et al 1996).

BOD and SS, therefore, provide useful ‘blanket’ indicators of the physiochemical state of water bodies. “Often in place of determining individual impurities it is more convenient to utilize ‘blanket’ determinants which measure a whole range of similar substances e.g. rather than determining individual organic substances in a wastewater sample it is customary to measure the amount of oxygen required to oxidize these substances. This oxygen consumption (BOD) then provides a measure of strength or

“polluting potential” of wastewater.” (Tebbutt 1992).

Suspended solids concentration is also a major parameter in the evaluation of domestic wastewater treatment efficiency.

“The suspended-solids determination is extremely valuable in the analysis of polluted waters... In stream-pollution-control, all suspended solids are considered to be settleable solids, as time is not a limiting factor. Deposition is expected to occur through biological and chemical flocculation; therefore, measurement of suspended solids is considered fully as significant as BOD. (Sawyer et al 1994).

At this point it is useful to distinguish between the ‘primary solids’ of the raw/unsettled sewage entering a treatment process and the ‘secondary solids’ in the settled sewage effluent exiting the treatment process. The following table describes this:

Table 3.2 Comparing Primary and Secondary Solids

Primary Solids	Secondary solids
The solid content of unprocessed (raw) sewage, which can be intercepted in a laboratory filter to give a suspended solids reading.	Due to the proliferation of microorganisms in sewage there is an accompanying proliferation of micro-carcasses, which are susceptible to filtration and can register as suspended solids. Rather than being present in the raw sewage influent these are actually generated by the primary treatment process.

**UK law requires that the consent for SS is met regardless as to whether these are primary or secondary.*

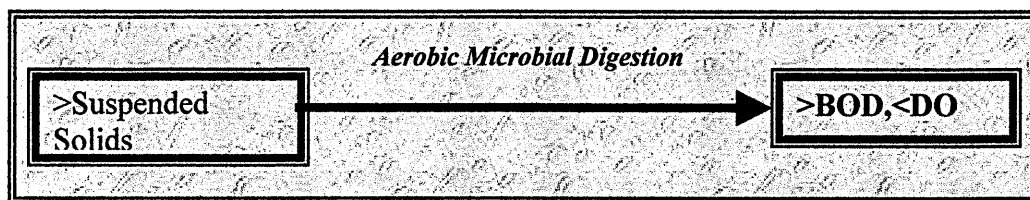
Water treatment systems are designed to reduce both suspended solids and biochemical oxygen demand as the release of SS and BOD into waterways impinges directly upon the aquatic ecology present by reducing the amount of available dissolved oxygen and light available to the system. Having said this, a certain level of organic loading or ‘fertilization’ of waterways can be advantageous as it provides nutrients (and the heterotrophic bacteria) to feed the aquatic food chains. A water body devoid of nutrients becomes ‘sterile’ and is unable to support life, this relates to the ‘trophic’* status of water bodies where ‘oligotrophic’ describes an aquatic environment with a low mineral

concentration whilst its opposite ‘eutrophic’ describes an aquatic system with a mineral abundance.(Organisms aquatic and otherwise can also be defined by a ‘trophic’ classification system but this relates to their nutritional requirements. This classification is detailed in Chapter 7.)

The value of allowing semi-treated organic waste to enter river courses from treatment works was the subject of a radio interview (“Today” programme-Radio 4- 10.08.98) where representatives of Trent Water, a company which has a lengthy history of indexing organisms and is concerned with fisheries as well as water treatment, discussed the merits of ‘naturally fertilizing’ river systems and the use of disused gravel pits for housing developing fish frie.

SS and BOD are interrelated in that the break down of organic suspended solids by aerobic microorganisms generates the BOD and thus reduces the amount of dissolved oxygen (DO) in the water.

Fig 3.2 Interrelationship of SS, BOD and DO



Levels of BOD are not always directly proportional to the size of organic solid being decomposed, as BOD is also dependent on the type of organic matter. For example, the rapidly decaying matter which comprises sewage might have a far lower BOD than say, an old oak tree which has fallen into a stream, but the time for aerobic digestion of the latter is also far greater and thus, at any time, the oxygen removed from the water for the digestion of the tree will be comparatively negligible compared with microorganisms rapidly decomposing sewage matter. In this way even though decaying sewage might have a lower BOD than that of the fallen tree it presents a far greater challenge to the higher organisms of the system (fish, crustaceans etc.) in terms of oxygen depletion. If micro-organisms require a lot of dissolved oxygen (DO) immediately to aerobically decompose sewage then the oxygen levels of the water body are reduced which can lead, in highly polluted systems, to there being an oxygen deficit for higher fauna and flora.

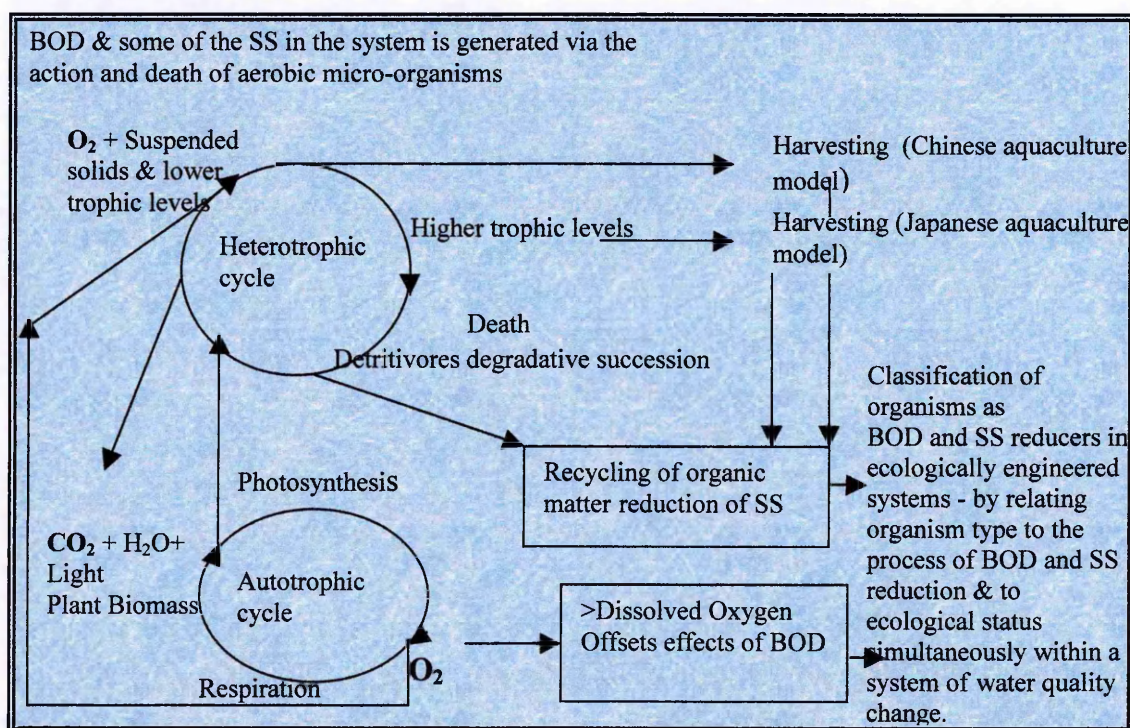
Whatever the composition of sewage that enters a water system it will, after a period of adaptation or acclimatisation, induce a ‘biocoenosis’ or a community of living organisms, which is optimally suited to the decomposition of specific pollutants. Ecological engineering of a water system therefore requires, as do biological treatment processes generally, the conversion of this natural self-purification process (in terms of eliminating oxygen-depleting substances) into a technical one.

Using suspended solids and biochemical oxygen demand as biochemical parameters with which to devise a biological classification system is relatively simple as both

parameters can be related to the trophic status of organisms within the foodwebs comprising the ecology of the system (Chapters 7 and 8).

Without going into detail it is sufficient at this point to acknowledge that the organic matter SS (which is comprised both of the sewage and the bacteria feeding upon it) feeds the heterotrophic cycles whilst the autotrophic cycles generate dissolved oxygen to counter the BOD. When the organisms within the system die they form the basis of degradative succession (heterotrophic succession) where detritivores (heterotrophs which feed on dead matter) feed in sequence, each group releasing nutrients that are utilized by the next group in the sequence until the resources are used up and the dead organic matter removed from the system.

Fig. 3.3 Ecological Cycles Relative to the Reduction of BOD and SS



3.4 Reiterating the Boundaries: 'Natural'/'Ecologically Engineered' Systems

To reiterate, "Natural" or ecologically engineered technologies comprise those water quality change systems which utilize 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 criticized for a number of reasons (Guterstam and Todd 1990):

- ◆ They create a lot of sludge as a by-product which is often contaminated and toxic and is thus environmentally stressful if disposed of by ocean dumping, land filling, spreading on agricultural land, incinerating or composting. All such processes bypass natural aquatic transformation cycles and encourage the recirculation of contaminants.
- ◆ They employ environmentally damaging chemicals e.g. aluminium salts to precipitate out solids, phosphorous and chlorine used widely in ammonia control and in faecal coliform* reduction.
- ◆ They fail to remove metals and synthetic organic chemicals as they do not incorporate the enzyme complexes found in higher aquatic organisms.
- ◆ They are costly in terms of capital cost, energy and labour.

The removal of settleable* solids by mechanical processes such as screening, flotation and the use of settlement tanks is not fraught with the engineering difficulties incurred with the elimination of fine suspended solids, colloidal matter and dissolved substances. These pollutants exhibit pronounced qualitative and quantitative temporal fluctuations. Monitoring them even with the most advanced analytical methods to produce a continuous record of such system dynamics is to all extents "practically" impossible. In this way the use of physicochemical (biochemical) technologies such as chemical coagulation which is itself substrate specific and requires continuous adjustment according to pollutant concentration is, for practical reasons alone, without investigating environmental impact, inapplicable to render a complete sewage treatment operation.

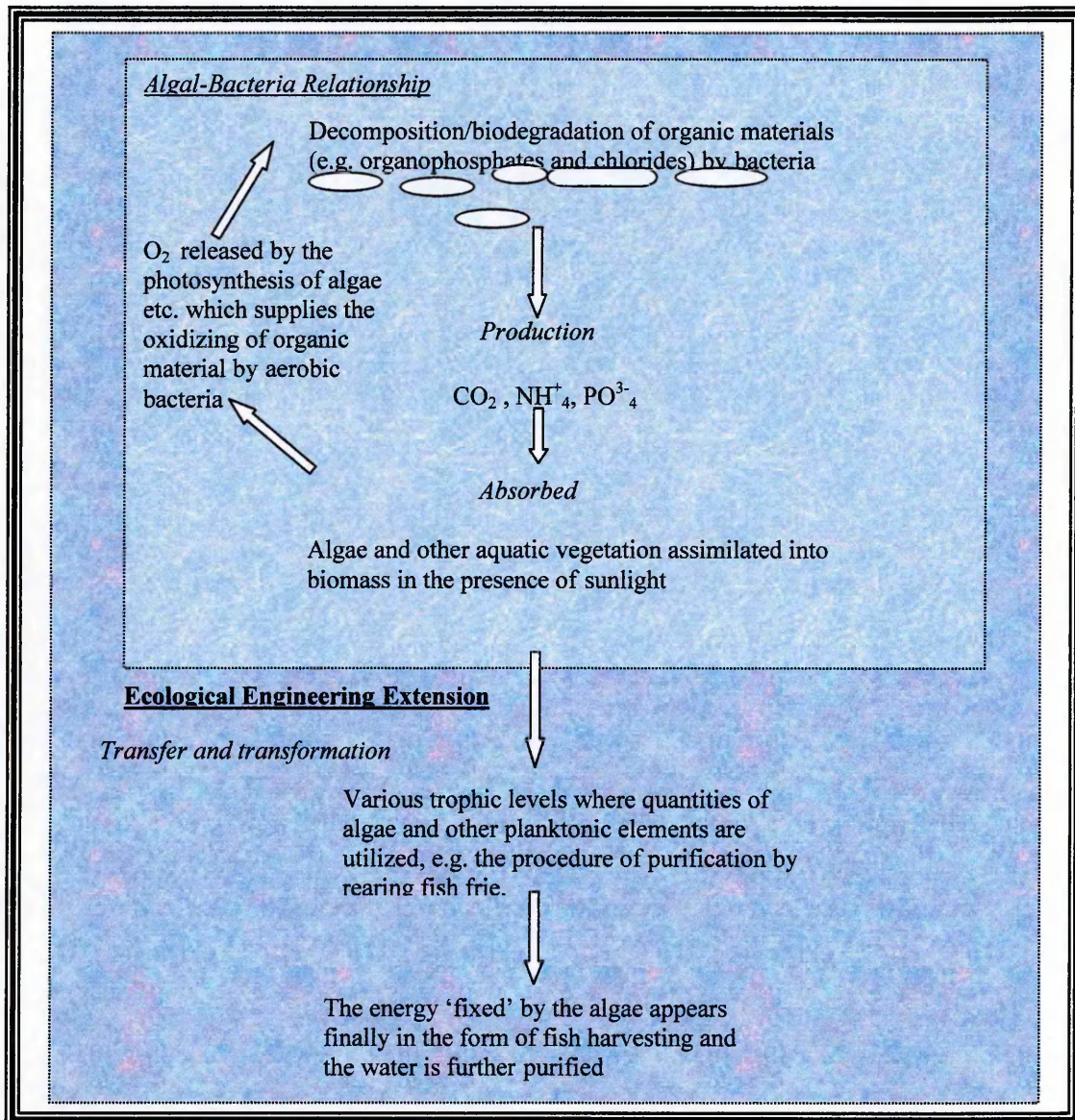
"As the limitations of biotechnology in contexts such as water treatment are experienced, ecological engineering which employs existing arrays of species, communities and ecosystems (biocoenoses) may receive more recognition and thus become incorporated alongside more traditional biotechnological techniques" (Porath 1996).

In other words utilising the 'self-purifying' communities (flora and fauna) that exist in natural water systems via ecological engineering of comparatively larger systems will allow the functions encompassed by a larger range of species (trophic ensemble) to be incorporated.

Ecological engineering generally can be regarded as designing functional 'natural' systems according to ecological principles both theoretical and applied. (Fig 2.4)

Figure 3.4 on the following page shows that traditional treatment concepts such as those of algal – bacteria sewage stabilization pond systems can be extended to include ecological engineering principles when for example aquacultural (integrated fish culture) systems are used. This resembles the C 19th European wastewater-fed, aquaculture engineering developments proposed by Oesten (1897, 1899a, 1899b) which are detailed in Section 4.2.3. of the next chapter.

Figure 3.4 How the Algal-Bacteria Relationship Forms the Possible Basis for Ecologically Engineered Systems of Wastewater Treatment



The following Chapter describes such a model of wastewater-fed aquaculture as a central Ecological Engineering example.

Chapter 4.

A Central Ecological Engineering Example: A Model of Wastewater-Fed Aquaculture

4.1 Introduction -Why Aquaculture is a Useful Ecological Engineering Example

4.1.1 Defining Aquaculture

In this chapter wastewater-fed aquaculture is used as a focus for the ecological engineering of wastewater treatment systems.

Aquaculture can be defined as the husbandry or the farming of aquatic organisms. It can be distinguished from the simple fishing of waters as it involves the actual culturing of organisms or *“Growing animals and plants in water, usually for food”* (Grant et al 1996).

Hill (1995) defined aquaculture as

“the farming of fish and other aquatic organisms (including pearls) and plants in either a saltwater (mariculture) or freshwater environment”.

4.1.2 Ecological Engineering of Waste Water and the Aquaculture Model

In a text entitled *“Ecological Engineering: An Introduction to Ecotechnology”* (1988) wastewater-fed aquacultural systems are referred to as “integrated fish culture management systems” by Jingsong and Honglu .

“In the broad sense, integrated fish culture is ecological engineering because semiartificial co-ecosystems (or combined production systems of aquaculture and animal husbandry, agriculture, and/or some other industry) make a nearly endless beneficial cycle of materials for the full multilayer and gradational utilization of various resources, including wastes within this co-ecosystems” (Jingson and Honglu 1988)

The developing practice of aquaculture is interesting for the following reasons:

- ◆ Although a very old practice it has only recently become an acknowledged activity, the farming rather than the simple fishing of waters.
- ◆ Aquaculture encompasses a need to study aquatic ecologies as profit-making (social and economic) organisations.
- ◆ It offers many useful insights into ecological relationships and their maintenance.
- ◆ It has lead via profit driven interest to the development of new ecological theories, which straddle social ones i.e. identified the need to define the utility of ecological systems to human society

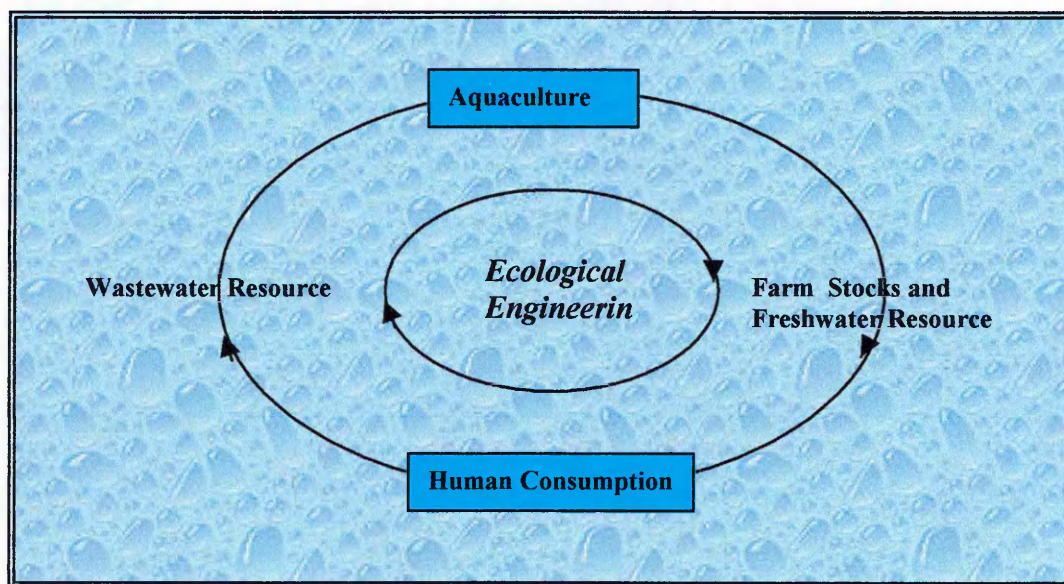
- ♦ Lastly, but most importantly, in the context of this thesis if linked directly to wastewater treatment it then becomes wastewater-fed aquaculture.

The practice of wastewater-fed aquaculture is also particularly interesting in the context of this thesis because

- ♦ It necessitates the operationalization of key biological concepts whilst simultaneously including humans in the ecological equation and as part of 'natural' systems
- ♦ It requires the combination of ecological and technological innovation and therefore requires an interdisciplinary research approach

This method of water treatment also fulfils the ecological engineering recycling criteria whereby waste is treated as a resource to generate a resource, which is then consumed to generate waste as a resource and *ad infinitum*. Also wastewater-fed polyculture aquacultural systems tend to be perceived as more ecologically complex than other wastewater treatment systems and so more data is generally available in terms of the types of organisms which contribute to the functional ecological complexity of the system.

Fig. 4.1 Wastewater-Fed Aquaculture - A Principle Ecological Engineering Model



In 1996 V. Govindan wrote that the main reasons for wastewater fishponds are; the utilization of nutrients, the production of protein, the recovery of costs for treatment facilities and for more environmentally friendly disposal of effluent.

4.1.3 The Scope of Aquaculture

Over the last decade the word 'aquaculture' has been used rather widely to

"denote all forms of culture of aquatic animals and plants in fresh, brackish and marine environments... For some, it means aquatic culture other than fish farming or fish husbandry, whereas others understand it as aquatic farming other than mariculture. It is also sometimes used as a synonym for mariculture" (Pillay 1990).

In this way the term aquaculture can confusingly appear an all-inclusive one although it does exclude the culture of essentially terrestrial plants (as, for example in hydroponics) or terrestrial animals. It is therefore important when describing a particular aquacultural system to define it using the following parameters

- ◆ The type of culture technique e.g. pond, raceway, cage, pen or raft culture.
- ◆ The type of principle organisms being cultured e.g. fish, oyster, mussel, shrimp, seaweed etc. and whether these are reared in monocultures or polycultures (Section 4.4).
- ◆ The culture environment e.g. fresh, brackish or salt water and also whether the system is wastewater-fed or not.
- ◆ The specific character of the culture environment e.g. cold-water, warm-water, up land, low land, inland, coastal or estuarine.

This research concentrates predominately on wastewater-fed, inland, fresh, cold-water, polyculture ponds, as it is these types of systems which are used as a case study in Chapter 9.

4.1.4 The Aquacultural Rationale

The rationale behind aquaculture is not restricted simply to its socio-economic and marketing advantages. There are also scientific principles that favour the culture of fish and shellfish (crustaceans). This is because such cultured animals are poikilothermic ('cold-blooded' or more correctly possessing a body temperature which varies according to their surrounding) and thus have relatively low energy requirements compared to endothermic ('warm-blooded') terrestrial mammals, birds etc.

"Fish are highest on the comparative list in terms of body weight gain to feed intake... Their protein efficiency ratio (wet weight gain per unit of protein intake) is either equal to or higher than for swine, sheep and steers" (Hasting and Dickie 1972).

Aquaculture is then, in terms of production, at least as successful a method of producing animal protein as the farming of poultry, pork and beef. As with terrestrial systems this productive success also depends on the culturing of appropriate species/variants and employing the correct farming techniques. Later this chapter will return to the following general rule;

“ Basically low trophic feeders can be cultured at lower costs than those which are higher in the food chain as the latter require a higher proportion of proteins particularly those originating from animal tissue. This is balanced however by the fact that the higher trophic species usually fetch greater prices in the market place which can compensate for the higher production costs. ” (in Pillay 1990).

This is relevant to both aquacultural systems whether or not, wastewater fed. The idea of trophic levels is explained in Section 4.3.1.

4.2 Background: A Brief History of Aquaculture

4.2.1 The Beginning : Chinese Aquacultural Development in Particular

Aquatic husbandry is an ancient practice dating back over two thousand years in China and eight hundred years in central Europe. There is evidence that commercial fish culture existed in China around 500 BC in the form of a text “*Classic of Fish Culture*” which is believed to be written around this time by Fan Lei, a Chinese politician-turned-fish-culturist. He cited his fishponds as the source of his wealth (in Ling, 1977).

The collection of carp fry from rivers and the subsequent rearing of them in ponds is described in some detail in later publications such as “*Kwei Sin Chak Shik*” (1243 AD Mit of the Sung Dynasty) and “*A Complete Book of Agriculture*” (Heu 1693 AD). It can also be traced back to ancient Egypt where a 2500 BC bas-relief of fish is believed to be that of tilapia raised in a pond.

Originally, in China, the only type of fish cultured was the common carp *Cyprinus carpio* (a native species which is tolerant to general physicochemical changes and thus fluctuating water qualities). Common carp were farmed in monocultures i.e. systems based around the culture of a single species. The species was introduced into several countries in Asia and the Far East by Chinese immigrants and later to Europe during the Middle Ages for culture in monastic ponds from where the practice spread to many countries. Relatively early on, in 618 AD, common carp culture actually lost its pre-eminence in China for reasons of a subtle phonetic/social nature (in Ling 1977; McLarney 1978). During this year the Tang dynasty was founded. The family name of the Tang emperors was ‘Lee’, which has the same sound as the Chinese word for common carp and so for a time it was considered sacrilegious to culture or eat this fish species. This meant that the aquaculturists of the time had to find different types of fish to metaphorically ‘fry’. Subsequently they looked towards other species of carp to culture. From this the rearing of other so-called Chinese carps came into being with; grass (*Ctenopharyngodon idellus*), silver (*Hypophthalmichthys molitrix*), bighead (*Aristichthys nobilis*) and mud carp (*Cirrhina molitorella*) cultures emerging.

It is impossible to ascertain whether this account is in actuality, simply a myth, perpetuated over time. There is another theory, which maintains that simple practical problems of separating larvae of different species of carp from rivers gave rise to the cessation of monoculturing common carp and subsequently led to the conception of the celebrated polyculture systems where more than one species is farmed from a single

system simultaneously. In most cases different carp species provided the general stock for polyculture systems.

*“Until very recent times, carp culture in ponds remained the mainstay of aquaculture in China, but for the introduction of tilapia (*Tilapia mossambica*) from Vietnam and the development of simple methods of oyster cultivation in certain foreshore areas of the coast” (Pillay 1990).*

By trial and error more and more complex polycultures were developed (with up to twelve different species of fish) with the expectation of increasing productivity in Chinese polyculture ponds.

As early as 200 AD aquacultural techniques spread to Japan via Korea. Chinese aquaculture still adopts traditional methods and continues to culture the carp (cyprinidae) family. In Japan different types of organisms are cultured including marine, anadromous* fish which migrate to rivers to breed, shellfish and plants. There are great technological and economic differences in the Japanese approach to aquaculture. The Japanese are quicker to adopt scientific methods which means productivity compares favourably to that of China but most Japanese products are not staple food sources being sold to middle and upper class consumers.

“The poor Chinese person eats a cultured fish as does the cultured Japanese whilst the poor in Japan feed on salt water fish taken by capture fisheries.” (McLarney 1978).

In both China and Japan the practice of breeding ornamental fish is an ancient one and includes most famously the rearing of goldfish (*Carassius auratus*).

4.2.2 The Development of Aquaculture Elsewhere

“Whilst Chinese immigrants were the focal points for most of the developments of fish farming in Southeast Asia, indigenous systems of Indian Carp culture seem to have existed in eastern parts of the Indian subcontinent in the 11th century AD.” (Pillay 1990).

Early practices of pen and cage culture of catfish appeared to originate in Cambodia (Kampuchea) and variations of this system arose in Indonesia for carp culture and in Thailand for the rearing of catfish *Pangasius*.

European aquaculture arose much later and also apparently independently of that in Asia. Although the first references date back to Roman and Greek times, indisputable aquacultural evidence does not emerge until the Middle Ages when various types of fish were kept in “stews” or castle moats (Prein 1988) in Central and Eastern Europe. This may have initially arisen from the simple “holding” of wild fish until they were ready for the table. Sooner or later the feeding of captive fish was initiated and European aquaculture was developed. Unlike the Chinese pond systems these European moats were not always fertilized. Instead the fish were fed with grains. Such cultures were

found to be less productive than their Asian counterparts. The next section details the development of wastewater-fed aquaculture in Europe.

The first fish to be cultivated was also the common carp and this continues today. Other cyprinids* such as pike and perch, catfish and eels were also cultured.

Another important family of freshwater fishes, which contains the species most valued by European fisherman, is the salmonidae family which includes species of salmon and trout.

“The propagation of trout, which has a fairly long history, originated in France and the monk Don Pinchot, who lived in the 14th century, is credited with the discovery of the method of artificial impregnation of trout egg” (Davies 1956).

Trout culture spread to almost all continents. This reflects the popular properties of trout as a sport fish and its widely accepted culinary superiority. Early efforts of trout culture were concentrated on repopulating water bodies for improved sport fishing but pond culture and other forms of intensive culture had to be developed to produce enough trout for market. Such commercial trout culture in fresh water was developed on a large scale in countries like France, Denmark, Japan and more recently Italy. Following on from this the culture of Atlantic salmon became a commercial success.

The first form of crustacean coastal culture appears to be oyster farming which the Romans, Greeks and Japanese are believed to have farmed first.

“Oyster culture in intertidal stretches is said to have been practiced in Japan around 2000 years ago. Aristotle mentions the cultivation of oysters in Greece and Pliny gives details of Roman oyster farming from 100 BC.” (Pillay 1990).

The culture of other molluscs such as clams and mussels occurred later and after the Second World War the culture of edible seaweed expanded spreading from Japan to other countries such as Korea, Taiwan and China.

4.2.3 Europe and the Development of Wastewater-Fed Aquaculture

European polycultures were developed far later than those in the East. During the middle ages in central Europe waste was often put into village ponds or castle moats for fish culture as it was already realised that by doing so the economic value of the ponds was enhanced.

“Village ponds could produce a gross fish yield of 600 kg/ha/season or more, in contrast to conventional carp ponds which produced gross yield of 150 kg/ha/season” (Hofer 1905).

The addition of wastewater to these systems also provided a more hygienic method of waste disposal than the alternative of the time which was the

“dumping of household wastes and excreta on the streets or other places close to houses which was then left to seep into the ground” (Keller 1918).

Wastewater-fed fish culture has, in European terms, a relatively long history in Germany. From 1887 to 1903, Oesten, an engineer with the municipal wastewater treatment services in Berlin, experimented with the reuse of effluents for fish culture (in Oesten 1904). He even patented a proposal (Oesten 1897, 1899a, 1899b), to reuse pretreated wastewater in a row of three serially connected ponds to produce fish although this was never actually implemented. These three ponds were to comprise;

- ◆ A “bacteria” pond which would be highly productive in microbial terms i.e. would produce microorganisms such as bacteria, alga, ciliate protozoa etc.
- ◆ A “crustacean” pond fed by the effluent from the first pond where zooplankton would be produced.
- ◆ A “fish” pond fed by the effluent from the “crustacean” pond.

“In biotechnology terms this represents an algal pond followed by a two stage harvesting mechanism for algal and bacterial biomass” (Prien 1996).

In Chapter 3 (Fig 3.4) ecologically engineered wastewater systems are also articulated as extension of the bacterial/ algal pond process.

The development of aquaculture in North America arose differently from this but was similar to the way in which trout culture evolved in Europe i.e. as a response to the depletion of gaming stocks during the middle of the last century. In this instance aquaculture has little to do with nutritional necessity or cleaning wastewater and equates to the luxury of recreational pleasure.

4.2.4 The Re-emergence of Aquaculture

The practice of aquaculture has re-emerged as a result of the over-fishing and depletion of stocks which has necessitated the need to

“enhance or create new stocks by human intervention” (Pillay 1990).

It is notable that the farming of aquatic systems has developed more slowly than that of terrestrial ones. Recently aquacultural developments have accelerated for the following reasons

- ◆ The increasing cost of fishing due to rising prices of such items as fuel, equipment and wages.
- ◆ Over-fishing in many areas due to growing demand and stock depletion
- ◆ Depletion of stocks due to pollution
- ◆ As a result of the above ‘wild’ aquatic animals have become more expensive and harder to obtain. (Swift 1993)

Although aquaculture is generally considered as part of fisheries science the distinction between the two terms 'fisheries' and 'aquaculture' is becoming larger (in Pillay 1990).

There is some conflict between the capture and culture fishery sectors, a terrestrial analogy could be the extraction and reforestation projects which form the basic elements of forest resource management. With respect to fisheries science the two activities need to be harmonized to provide an integrated development policy programme.

More recently there has been a worldwide increase in both small and large-scale aquaculture projects.

"The years 1960-85 saw a rapid increase in the commercial development of aquaculture ...at the same time there has been considerable growth in traditional semi-subsistence aquaculture" (Swift 1993).

4.3 Aquaculture Systems and Basic Ecological Principles

4.3.1 The Basic Ecological Principles

"It is important for any future farmer to understand at least the basis of the functional requirements of the animal he/she wishes to farm. Good husbandry of any animal requires that the farmer understands the interplay between the animal and the environment in which it is kept; how the environment affects the animal and the basis of established aquaculture practices." (Swift 1993).

Simultaneously the reverse/feed back of this process i.e. the effect organisms have on the environment in which they exist is important to ecologically engineered systems. An organism's activity within any biological system comprises two main functions, which alter the state of the system, i.e. the removal and the replacement of nutrients. It is upon this that all other intrinsic physiological, physiochemical changes of the system rest.

An aquatic organism's water cleansing property will depend upon

- ◆ The means by which it obtains its life energy
- ◆ The end products of its metabolic activity

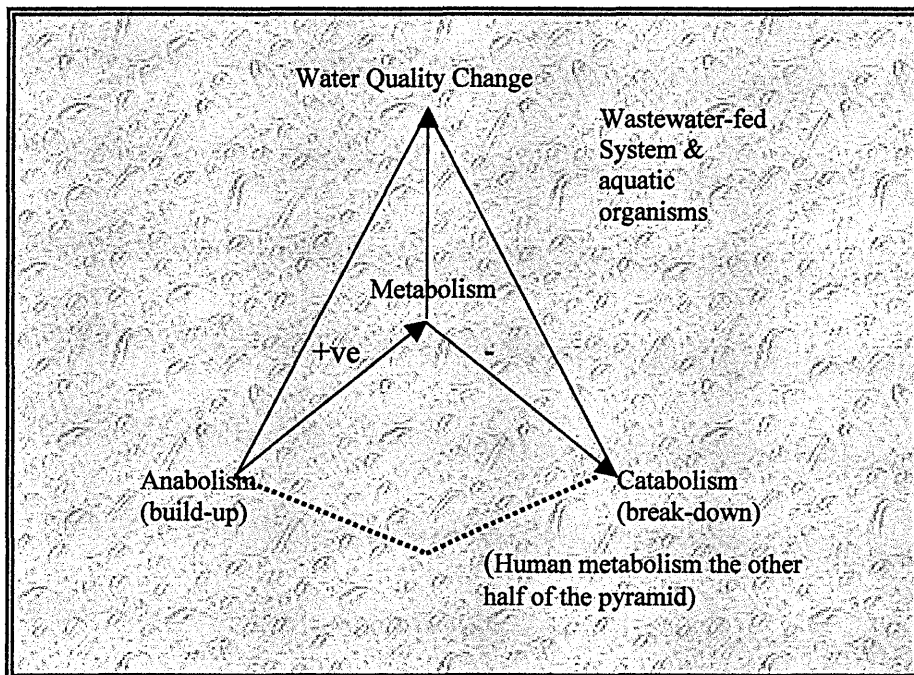
In a wastewater-fed aquaculture system a metabolic loop is set up whereby the metabolism of organisms intrinsic to such water systems is used to metabolise the waste products of human metabolism. This can be symbolised as two halves of a whole pyramid of a water quality change system, Fig. 3.2 (see also Figs.4.1, 4.2)

"Waste water treatment may be regarded as resulting from the activity of organisms on one component of their environment- the waste being treated"
(Hawkes 1965)

Organisms do not exist in isolation and in addition to the above biological principles the way in which organisms interact with one another and their environment, that is the

ecology of the system, is also intrinsic to understanding the functioning of aquaculture systems.

Fig. 4.2 The Water Treatment Pyramid



Aquaculture is a useful paradigm for ecological engineering as it utilizes many basic ecological principles such as

- ◆ Trophic levels, foodwebs and pyramid of numbers
- ◆ Limits of tolerance corresponding to Liebig's minimum law (1840) and Shelford's (1911) Law of tolerance
- ◆ Resilience, stability, nonstability and the equilibrium/nonequilibrium hypotheses.

Taking each of these principles in turn:

i) Trophic Levels and Foodwebs

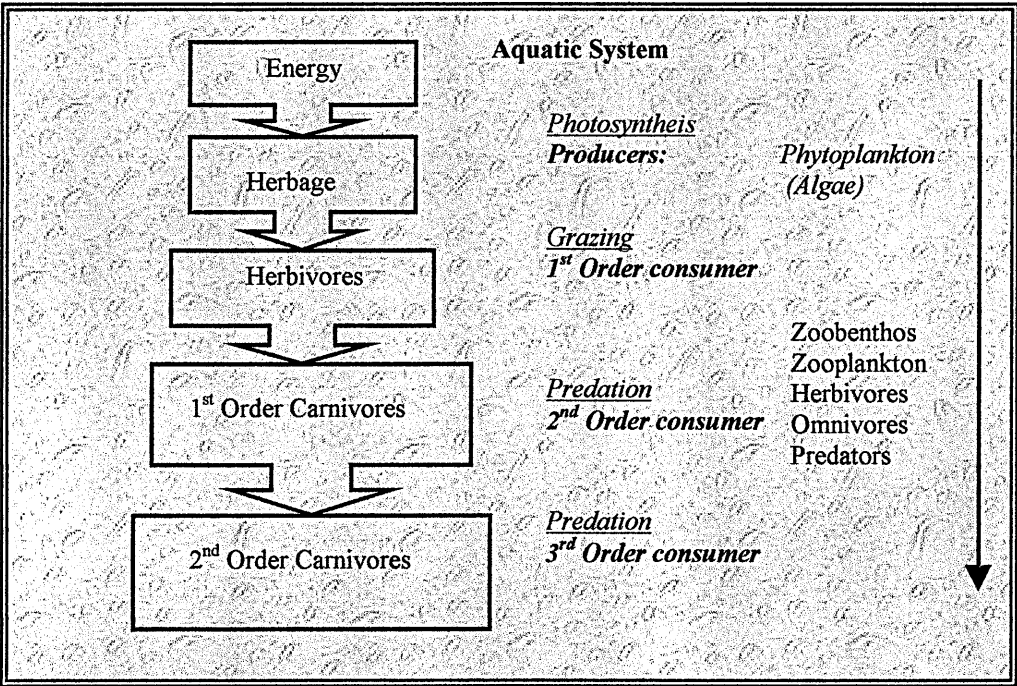
The trophic level of an organism can be defined as

"a step in the transfer of food or energy within a chain (of living organisms)"
(Allaby, 1998).

A foodweb is a system of interlocking food chains, which comprise the energy transfer of a living community. *"A food chain is essentially an energy conversion scheme"* (Porteous 1996).

It comprises a series of organisms through which energy is transferred. Each link in the chain represents a trophic level which feeds upon the link preceding it except in the case of the basal link, which comprises ‘herbage’, namely vegetation.

Fig. 4.3 Trophic Levels and Energy Flow



Food chains and trophic levels are of course a vast simplification of what are actually complex food webs, most organisms consume a variety of organisms.

“The classification of organisms by trophic levels is one of function and not of species as such, any given species may occupy more than one trophic level”
(Krebs 1985).

The idea of trophic relationships and a “*taxonomic theory of ecology*” (Cousins 1996) is returned to in Chapters 7 and 8.

In addition to the basic trophic relationships complex ecological interactions also need to be taken into account, for example, symbiosis, competition both intra and interspecific, association, parasitism and mutualism. The complexity of food webs can be crudely expressed by a measure called connectance which is the number of realised interspecific interactions (interactions between different species) divided by the potential number of specific interactions.

Broadly speaking within trophic levels it is possible to recognize groups of species or groups, namely ‘guilds’ (Putman, 1994) , which are exploiting a common resource base in a similar fashion. Such guilds may serve to pinpoint the functional roles species play in a community. This research is concerned with a functional classification and in

Chapter 8 'ecotaxa', which are guilds specific to this research, are identified using the context of organisms as water quality changing systems specifically with respect to biochemical oxygen demand (BOD) and solid removal (Sections 1.3.3, 3.3). These two chosen water quality parameters, biochemical oxygen demand and suspended solids define the 'organic pollution' of a water body which is related to immediate physical changes in water quality which then facilitate subsequent chemical changes in microorganisms and macroinvertebrates (Section 3.3). In this way the main 'organic pollutants' BOD and SS are the catalysts for change at all organizational levels from physicochemical to ecological. It is, therefore, unsurprising that traditional treatment works were designed primarily to reduce these pollutants.

ii) Limits of Tolerance

Baron Justus Von Liebig (1803-73), a German chemist, published in 1840 "*Die Organische Chemie in ihrer Anwendung auf Agrikulturchemie und Physiologie*" (Organic Chemistry and its Application to Agricultural Chemistry and Physiology). In it he maintained that plant growth is limited by the availability of the scarcest essential nutrient.

Liebig's law of the minimum can be stated as

"the rate of growth of a plant, the size to which it grows and its overall health depend on the amount of the scarcest of its essential nutrient that is available to it" (Allaby 1998).

This has been subsequently extended to include animal as well as plant species.

Liebig's Minimum law can be related to Shelford's law of tolerance proposed in 1911 by the American ecologist Victor Ernest Shelford (1877-1968). He maintained that the presence and success of an organism depended upon the extent to which a complex of conditions is satisfied e.g. climatic, topographic and biological. The absence or failure of an organism can be controlled by the qualitative or quantitative deficiency or excess of any one of several factors, which may approach the "limits of tolerance" for that organism.

The biochemical parameter central to the work in this thesis, which relates to the biological tolerance of the aquacultural organisms concerned, is the biochemical oxygen demand (BOD) of the water.

"the oxygen that micro-organisms require to break down organic matter" (Grant et al 1996)

This oxygen consumption (BOD) then provides a method of measuring strength of the

"polluting potential" of wastewater." (Tebbutt 1992).

For example different types of cultured fish can tolerate different levels of biochemical oxygen demand beyond which they expire

Table 4.1 Different Levels of Biological Tolerance to BOD in Culture Fish

Fish Species	Silver Carp	Bighead Carp	Grass Carp	Black Carp	Common Carp	Wuchang Fish
Highest tolerated BOD mg/l	30	30	15	15	30	30

(Daugovish, 1998).

Suspended solids concentration is also a major parameter in the evaluation of domestic wastewater treatment efficiency.

“The suspended-solids determination is extremely valuable in the analysis of polluted waters... In stream-pollution-control, all suspended solids are considered to be settleable solids, as time is not a limiting factor. Deposition is expected to occur through biological and chemical flocculation; therefore, measurement of suspended solids is considered fully as significant as BOD.
(Sawyer et al 1994).

iii) Resilience

“Stability is an equilibrium centered concept which many Ecologists focus on when exploring the dynamics of populations and communities” (Krebs 1985).

In 1973 Holling introduced the idea of resilience as an alternative way of looking at populations and communities of organisms.

“Resilience is a measure of the ability of a system to persist in the presence of perturbations arising from weather, physical-chemical factors, other organisms or human activities...resilience is a measure of the probability of extinction”
(Holling 1973).

This thesis looks at the fertilization of water as not simply a perturbation but as a principle driving force in the generation of aquacultural, water quality changing systems. In managed systems such as ecologically engineered systems for wastewater treatment knowing the bounds of resilience is important because some ‘stable’ communities are more useful to man than others. However a community which fluctuates a lot may be resilient despite its apparent instability (Section 10.6).

There are two main opposing views on the organization in terms of diversity and abundance (see also Chapter 9 and 10) of ‘natural’ communities and these are described in the Table 4.2:

Table 4.2 The Equilibrium and Nonequilibrium Hypotheses of Organization in 'Natural' Communities

Equilibrium Hypothesis	Non-equilibrium Hypothesis
"The more conventional view is a statement of the "balance of nature". Local populations are held in check by natural forces of competition, predation and mutualistic interactions. Global stability is the rule and disturbances are damped out. Species diversity is determined by niche diversification, and each species is competitively superior in exploiting a particular habitat." (Krebs, 1985)	"The less well accepted view which states that species composition of a community is always changing and never in balance. There is no global stability for communities in the real world, and persistence or resilience is a more relative measure" (Krebs, 1985) The most probable mechanism for this results in a further hypothesis the "Intermediate disturbance hypothesis" (Connell, 1978).

It should be noted that there seems to be some discrepancy between the levels of ecological organization which the two opposing hypotheses are describing. Whilst the 'Equilibrium Hypothesis' seems to be describing more 'local' interactions involving populations, the 'Non-equilibrium Hypothesis' refers to the more 'regional' interactions comprising community structure. This would indicate that the validity of each hypothesis is dependent, as ever, on scale.

More recent work suggests that the emergence of non-equilibrium dynamics as an acceptable hypothesis actually has more to do with the new perspectives which arise when a less conventionally ecological approach to studying natural systems is taken. This is interrelated with the ideas introduced in Chapter 2 whereby issue driven research often requires a different mind-set from that generated by the conventional separation of scientific disciplines.

"The recognition of non-equilibrium dynamics in a variety of (although by no means all) settings challenges some basic, often deeply embedded, conceptions of naturalness, balance, and order and suggests new ways of thinking about resource management and policy that were often rejected by more conventional ecological perspectives" (Scoones 1999)

The 'Intermediate Disturbance Hypothesis', which could form a mechanism for the nonequilibrium hypothesis, states that

"High species diversity is maintained at moderate/medium levels of disturbance. If disturbances are frequent only colonizing species of quick maturation will occupy a site (that is r-select species type). At the other extreme if disturbances never occur than the competitor that is the most efficient or aggressive (k-select species) will eliminate other species." (Connell 1978).*

This hypothesis assumes that every community has a potential dominant that would form a monoculture if given enough time without disturbance. Relating this to wastewater treatment...

"There is an extensive body of literature on the relationship between ecological stability and diversity. It seems intuitively clear that a more biologically diverse

treatment system is likely to be inherently more stable than one of lesser diversity. Unfortunately a simple relationship between diversity and stability is not only equivocal, but contrary to both mathematical models and empirical evidence...If stability is to be linked in some convincing fashion to diversity within a treatment ecosystem, then diversity must be a quality entailing some measure other than mere numbers of species” (Austin and Tchobanoglous 1996).

This leads to the idea that stability (non-stability) needs to be defined in terms of the relevant physiological and structural diversity provided by living communities and not simply species diversity (although the two are to a certain level inseparable).

The idea of variety in terms of species and functional diversity in terms of relevant biochemical change is a central theme of later chapters. Chapters 6 and 7 investigate the classification of organisms as biologically and ecologically functioning units respectively whilst Chapter 8 looks at a new classification system or ‘ecotaxonomy’ attempting to classify organisms in terms of their functional diversity in ecological engineering terms. In Chapter 9 wastewater-fed aquacultural organisms are reclassified according to the new ecotaxonomy.

Ecological theories aside there are economic reasons why stable monoculture systems are not the most profitable when it comes to aquacultural systems and these are discussed in the following sections.

4.4 Why Polyculture Replaced Monoculture Aquaculture Systems

4.4.1 The Benefits of Polyculture

Polyculture can be defined as

“the simultaneous culture of two or more aquatic species with different feeding habits” (Daugovish 1998)

Polyculture appeared in China more than a thousand years ago. The practice then spread throughout South East Asia and into other parts of the world.

“The motivating principle is that fish production may be maximized by raising a combination of species with different feeding habits. The mixture of fish gives better utilization of the available natural food entering and produced in the pond.” (Daugovish 1998).

This is because

“most fish feed on selected groups of organisms. Polyculture should combine fish with different feeding habits in proportions that effectively utilize the existing diversity of nutrients in the water” (Bocek 1996).

The ecotaxonomic developments of Chapters 8 and 9 are centered on the feeding habits of different aquatic organisms in order to reclassify them, functionally, as the separate

components creating the functional diversity (in water treatment terms) of the ecology. The idea of biodiversity and functional diversity are explained in Chapters 9 and 10.

When assessing the benefits of stocking more than one species in a polyculture rather than a monoculture it is useful to realise two basic principles which can be applied to aquaculture;

1. A body of water is a three-dimensional growing space. To treat it like a field, by planting only one type of crop, is likely to result in wasting the majority of that space.
2. Any fertile pond will produce a number of fish food organisms. However most fish are not omnivorous but are rather selective in their diet. Stocking a single species wastes not only space but also food.

“Polyculture is one of the important ecotechniques for integrated fish culture. The principle purpose of polyculture is to bring the productive potential of the water body into full play to ensure a good harvest. Thus the prerequisite of polyculture is as much vertical utilization of various strata of water in the fish pond as possible ... a mixed community of fishes (and other organisms) in the same pond will require species that dwell in the upper, medium and lower layers of the pond, as well as species with different feeding habits, that is, plankton feeders (planktivorous types), herbivorous fishes, benthic molluscs feeders, benthos* feeders and omnivorous feeders.” (Daugovish 1998).*

The above principles i.e. the spatial component in addition to feeding habit are also included in the formulation of the afore mentioned new taxonomic system, this can be found in Chapter 8.

Generally one to three species of fish are reared as the dominant stock in a polyculture and the others are termed secondary or companion species.

In China generally between five and eight species of fish are stocked although as many as ten species are sometimes reared. Table 4.3 on the next page illustrates such a polyculture stocking system.

4.4.2 Example of a Chinese Polyculture System

A typical Chinese Polyculture will comprise the following

Table 4.3 Chinese Polyculture Species

Fish Species	Eating Habits
Grass Carp (<i>Ctenopharyngodon idellus</i>)	Consuming greenery provided by the farmer. (surface feeder)
Big Head Carp (<i>Aristichthys nobilis</i>)	Midwater filter feeder with a preference for zooplankton
Silver Carp (<i>Hypophthalmichthys molitrix</i>)	Midwater filter feeder with a preference for phytoplankton
Mud Carp (<i>Cirrhinus molitorellus</i>)	Feeds on benthic animals and detritus including Grass Carp faeces. (bottom feeder)
Common Carp (<i>Cyprinus carpio</i>)	Feed on benthic animals and detritus including Grass Carp faeces. (bottom feeder)
Black Carp (<i>Mylopharyngodon piceus</i>)	Feeds on molluscs. (bottom feeder)

Including the above variety of fish species ensures that several trophic niches are filled simultaneously.

4.4.3 Factors Defining the Type of Fish Stocked in a Polyculture

The decision as to which type of fish are reared as dominant and the number of individuals stocked in a system is dependent on the following factors

- ◆ Availability and quality of local feed for the various feeding habits of the reared fish.
- ◆ Biological characteristics of the fish especially those associated with feeding and habitation.
- ◆ The economic/commercial value of the different sorts of cultivated fish.
- ◆ The condition of the pond especially its fertility which has a large effect on the composition of the plankton and the production of natural food organisms for the fish.
- ◆ The source of fingerlings (juvenile fish)
- ◆ Geographical location.

4.4.4 Pond Fertility and Polyculture Type

The condition of the pond in terms of its fertility, that is the level of nutrients, predominately nitrates and phosphates, also defines the type of aquaculture. Table 4.4 on the next page relates pond fertility to the type of polyculture present;

Table 4.4 Pond fertility and Type of Polyculture

<u>Water comparatively fertile</u>	<u>Water comparatively infertile</u>
Rich in plankton and organically loaded	Aquatic and /or land grasses are abundant
Planktivorous fish dominate whilst secondary species may be herbivorous species such as grass carp, Chinese bream, Wuchang fish or omnivores and benthic* (bottom) feeders such as common carp, crucian carp, and black carp, which feed mainly on snails/and or clams.	Herbivorous fish dominate such as grass carp and Wuchang whilst the companion species are planktivorous fish such as silver carp, bighead carp, common carp, crucian carp and a few black carp. Another type of polyculture raised in infertile water has black carp reared as the main species in regions of abundant molluscs, especially snails and clams. Here companion species are silver carp, bighead carp, Chinese breams, Wuchang fish and common carp

The idea of pond fertility leads full circle back to the concept of wastewater-fed aquaculture and central to this is the realization of aquatic ecologies as physical hierarchical water treatment systems.

4.5 Wastewater-fed Aquaculture and Ecologies as Cleaning Hierarchies

4.5.1 Processes in Wastewater Fish Ponds

“Wastewater-fed aquacultures are mainly production plants: biomass and cleared wastewater are produced through a constructed aquatic food web” (Staudervann and Junge 1991)

The removal of wastes from an ecologically engineered water treatment system can be correlated to the trophic relationships in food chains, not only because organisms at higher levels consume ‘contaminated’ organisms at lower levels and thus remove nitrogen, phosphorous and suspended solids by incorporating them into their own biomass, but also by processes of physicochemical transformation and excretion. Contaminants are trapped in settleable form as the mucus bound faecal products of egestion i.e. as the faeces of aquatic organisms. This, then sinks from the water column and via sedimentation procedures can be removed from the aquaculture system as a whole.

4.5.2 Main Pathways for Waste Removal

There are three main pathways for the removal of waste (organic material) in wastewater-fed aquaculture systems

1. Waste materials are directly consumed by the fish. This only occurs in fairly diluted wastewater where the waste concentration does not interfere with fish life and is

acceptable if the concentration of toxic compounds in fish tissue is within defined standards.

- 2. Nutrients released from the waste materials accelerate autotrophic production and subsequently promote the growth of other organisms, which are consumed by fish of different ecological niches.
- 3. Waste serves as a base for heterotrophic* production where bacteria and protozoa are grown on the surface and are in turn eaten by the fish.

4.5.3 Comparing Sewage Sludge to Animal Manure Water

It is important at this point to note the difference between ‘animal manure water’ (diluted organic waste from farms etc.) and ‘sewage sludge’, both of which can be used to fertilize aquaculture systems. This thesis centers on case studies, which look at the organic loading of aquacultural systems via sewage treatment as opposed to farm effluent

Table 4.5 Differences between ‘Animal Manure Water’ and ‘Sewage Sludge’

Animal Manure Water	Sewage Sludge
>proteins	>nutrients (N,P)
>lipids	>trace metals (Cu, Pb, Zn, Cd)
> minerals	>hormones
Commonly used as pond fertilizer	>pathogens
	Value of amino acids is claimed to be in a more sufficient amount for fish consumption
<hr/>	
(> = more than that of sewage sludge)	
(> = more than that of animal manure water)	

“On the face of it sewage sludge might appear to be slightly dangerous but when the concentrations of metals (Cu, Fe, Zn, Mn) are traced through the food chain of the pond: sludge elements – green algae – freshwater shrimp – carp, it can be noticed that as the chain progresses the concentrations decrease” (Daugovich 1998).

Pathogens from the sludge can be eliminated via composting or thermal treatment. Minimal treatment in a stabilization pond, that is one day in an anaerobic facility or five days in a facultative pond prior to discharge into the fishpond can, according to World Health Organization Guidelines for the use of wastewater in aquaculture (WHO:1989), render any fish from the pond microbiologically safe for human consumption (faecal coliforms per 100ml pond water would be <1000).

4.5.4 Organic Loading

It is the organic loading of water which is of primary interest in the context of this thesis, that is the increase in biochemical oxygen demand (BOD) and the subsequent decrease in dissolved oxygen (DO) which arises from the continued activity of aerobic bacteria upon solids when wastewater is released into pond or natural fresh water systems. The reason this is of principal interest instead of say levels of nitrate and

phosphates is that traditional wastewater treatment facilities were designed originally to reduce the biochemical oxygen demand of the effluent and so protect the receiving water body against

“an encroachment on it’s oxygen balance.” (Mudrack and Kunst 1985).

It is not surprising, therefore, that the performance of a treatment plant is gauged by this BOD₅ decrease and is thus designed primarily upon the basis of BOD loading. Process variations which exceed this simple BOD₅ elimination and are termed advanced sewage treatment methods.

“biologically refractory materials (collectively expressed as COD) and phosphorous and nitrogen i.e. eutrophication inducers are termed advanced sewage treatment methods.” (Mudrack and Kunst 1985).

This research is interested in ecological engineering as opposed to biotechnological approaches to wastewater treatment and therefore relates to a different set of agendas than those low volume, high energy facilities which comprise traditional treatment plants.

Organic loading BOD was the obvious parameter to use initially because:

- ◆ As the initial traditional water quality parameter to produce consent criteria, it has been key to the development of the present water quality framework. Any ecological engineering potential for water treatment will have to exist in a future evolved from this scenario.
- ◆ Oxygen status of water ways is fundamental to the ecology of the system and thus to ecological engineering.
- ◆ Eutrophication as a result of overloading with nitrates and phosphates ultimately results in changing this oxygen status.
- ◆ The organic loading (fertilization) of water ways is pivotal to the development of aquacultures and in that way acts as the fulcrum between sewage disposal and aquatic farming.

Hard technological advancements of water treatment facilities such as the development of more efficient biofilters are ongoing. Such essential research though predominately of a biotechnological and chemical nature still has to exist within a changing environmental arena. Wastewater-fed aquaculture still forms, in global terms, a large percentage of water quality control.

4.6 Comparing Chinese and Japanese Aquacultural Models

4.6.1 The Two Main Aquaculture Models

The parallel and continuous development of aquaculture in different countries and continents provided two main classes of aquaculture model. These can be termed the Chinese and the Japanese socio-economic models after the countries in which they were originally developed.

The former is driven by the need to produce a quantity of protein whilst the latter is driven primarily economically to produce quality luxury food. Japan, like England having a high coastline to inland ratio can get the majority of its fish protein from the sea (mariculture).

Aquaculturists recognise that there is an interrelationship between the socio-economics of the country/region and the trophic level of organisms chosen to be aquacultured. For example in China where the aquaculturist must seek to maximize the production of human food per unit water, whilst keeping the price of the resulting product below a certain maximum, fish species have to be chosen which occupy lower trophic niches as such herbivorous types tend to be larger and also do not require stocking the system with additional prey fish.

Whereas in the Japanese model, which “developed” western culture tends to emulate, then only the organisms of higher trophic levels are harvested (e.g. ‘piscivorous’, game fish).

In both scenarios the feeding of lower trophic organisms, whether harvested or not can, in addition, have a synergistically advantageous effect in that their fodder, if say sewage, might actually be more expensive to dispose of in other ways than via using it to support the developing aquasystem.

This may all seem on the face of it far removed from the situation in the United Kingdom or North America as in such so called ‘developed’ countries there is already an excess of protein-based farmed food. In research terms, exploring wastewater-fed aquaculture systems is of universal interest because it enables the investigation of aquatic organisms as functional units in terms of both their farming and water treatment potentials simultaneously. Not only that, the Chinese and Japanese models, which have emerged as the result of centuries of aquacultural experience, illustrate the socio-economic implications of basing ecologies upon either the mass production of higher or lower trophic level organisms. As such these models can be used to anticipate the socio-economic effects of choosing one type of culture over another. The trade-offs depend on the socio-economic status of the region involved. Accepting the general laws of energetics, independent of the product costings, if an aquaculturing pathway is used which relies on cultured (farmed) grains in fish feed or the conversion of low cost fish meal to produce expensive fish are used, the actual amount of protein for human consumption is reduced. This is why at a global level producing more ‘luxurious’ items is environmentally costly. Energy intensive aquaculture is also a source of pollution.

4.6.2 The Western Aquaculture Paradigm

From section 4.2.3 it can be seen that the incorporation of fish culture into the process of modern sewage treatment is actually an European contribution. In Germany and Poland this is now a considerable source of food, revenue and improved sewage treatment.

In his text McLarney (1978) investigated the role freshwater aquaculture can play in North America which at the time was following the Japanese model. He argues that although temperate developed countries usually follow this Japanese aquacultural pattern, they are, by doing so, missing much of the benefits from the Chinese system.

It is useful to compare aquaculture in America and China by looking at respective trophic representations using the idea of "Pyramid of numbers" of organisms stemming from primary productivity which is equal. (After McLarney 1978). This can be found in Fig 4.4 at the end of this section.

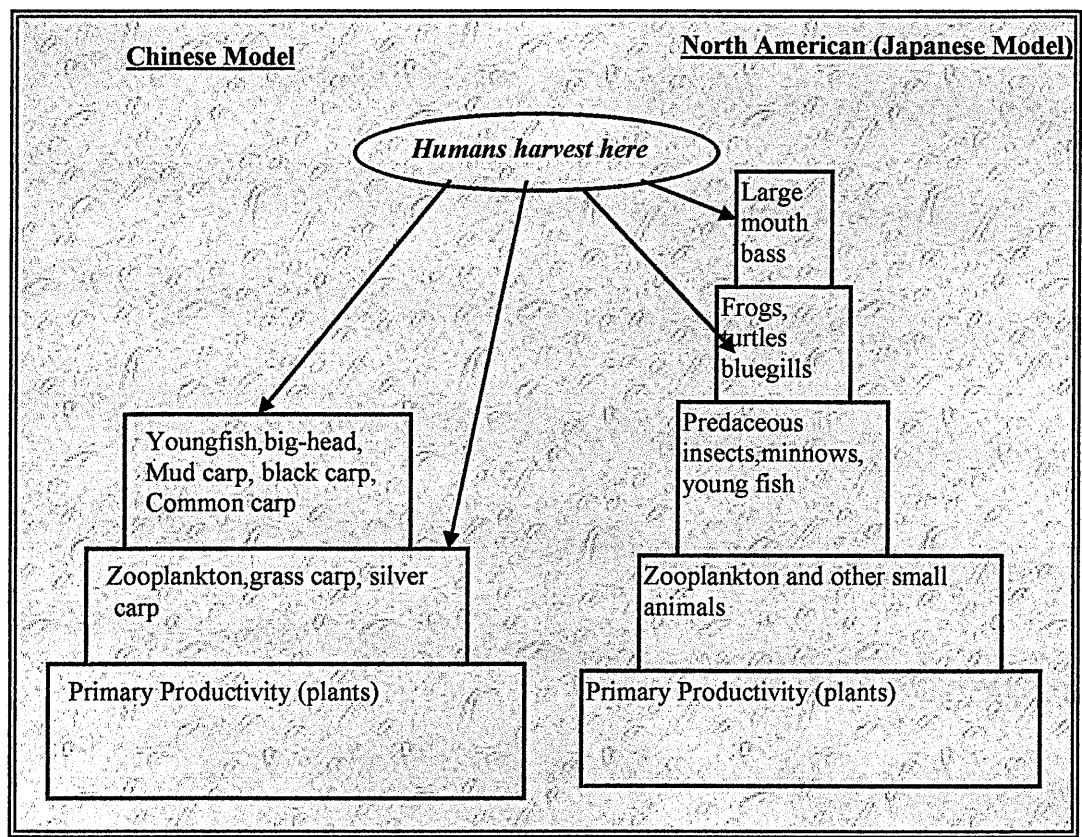
The Japanese model has been adopted by more affluent nations and can be seen to apply in the case of North American polyculture systems.

The American farm pond, which is based on the Japanese model of polyculture, has a much longer food chain than that of the Chinese aquaculture and the organisms are farmed from the top by harvesting predatory fish. In the Chinese pond the two top trophic levels are entirely absent with the human food being taken closer to the bottom of the chain from fish which are as large as the American bass and bluegill, but which consume plants and/or plankton. The presence of such organisms at lower trophic levels large enough to be worth harvesting means that a greater percentage of the total pond biomass is "harvestable" i.e. the system is more efficient in terms of creating nutritional wealth for humans. The lower productivity of the Western scenario, due to the lack of large fishes, which are low on the food chain, is not simply the fault of the ecological engineers who thought up the model/farm pond programme, it is also due to plate tectonics and the subsequent evolutionary geomorphology of the continent i.e. North America has very few large herbivorous or plankton feeding fish.

Other things, which negatively effect productivity when using the Western Pool model, are:

- ◆ The stocking system is oversimplified and reduced to a formula when every situation needs to be managed with its individual characteristics in mind.
- ◆ American ponds are not designed in accordance to relevant methods of fish harvesting.
- ◆ Due to the sporting mentality of Americans ponds tend to be stocked exclusively with predatory fish because they are fun to hook and line. They are managed with recreation and not food production in mind.
- ◆ Bigger specimens look better in a show cabinet despite the fact that smaller ones often taste better.
- ◆ American farmers will generally not fertilize the ponds as they consider it unhygienic.
- ◆ The Chinese have far greater aquaculture experience (over three thousand years) compared to that of Western society.

Fig 4.4 Comparing the Chinese and N. American Ecological Aquacultural Pyramids



4.6.3 Aquaculture Models: Concluding Remarks

The delineation of aquaculture into two general models is actually a vast simplification. But it does offer a good insight into a ‘means to an end’ mentality whereby ecologies, natural and engineered, are shaped for a defined result.

The fundamental differences found within the oriental origins of aquaculture is that the Chinese side is driven fundamentally from the stand-point of acquiring maximum nutritional value from the system. Due to it’s relatively longer coast line the Japanese model of aquaculture is driven via the economic of producing luxurious highly marketable products.

In western society ecologically engineered aquaculture systems have a tendency toward the Japanese paradigm with expectations of a recreational nature i.e. they are geared toward pursuits such as angling. The Chinese model and variations of it have much to offer, however, when it comes to the reclamation of natural river ecologies and in the task of ecological buffering of wastes from treatment works etc. At present in many ‘developed’ countries public perceptions often prevent humans consuming organisms of lower trophic levels which are fed/grown on wastes.

"Public attitudes to eating products grown in waste water, particularly sewage effluents, can be a problem and solutions have to be found on the basis of socio-cultural ambience and should include public education and product promotion."
(Pillay 1990).

It needs to be remembered that certain toxins actually biomagnify* up through food chains and so the consumption of organisms of higher trophic levels is not always a safe option.

Encouraging the growth of ecological systems containing a variety of organisms of different trophic levels also enhances the flexibility of systems to adapt to change in addition to offering aesthetic and educational benefits.

Aquaculture is not without its own set of environmental problems. Ecological concerns are the same as for any intensive farmed catchment and can include polluting downstream areas especially when the 'aquabusiness' is following the model of Japanese aquacultural development and using massive nutritional supplementation.

Chapter 5.

The Research Design Process

5.1 Introduction

This chapter details the synthesis of the research design. From previous chapters it can be seen that there is a continuous interplay between the substantive and epistemological objectives of the research. In order to clarify this Fig. 5.1 (Cordey-Hayes,2000) articulates this interplay between the epistemological and substantive components which are intrinsic to both the research design and outcomes.

Section 5.2 details the components which comprise Figure 5.1. (Page 64) the section numbers are included on this figure which thus depicts the entire research design process.

5.2 Detailing the Components comprising the Research Design

5.2.1 The Issue

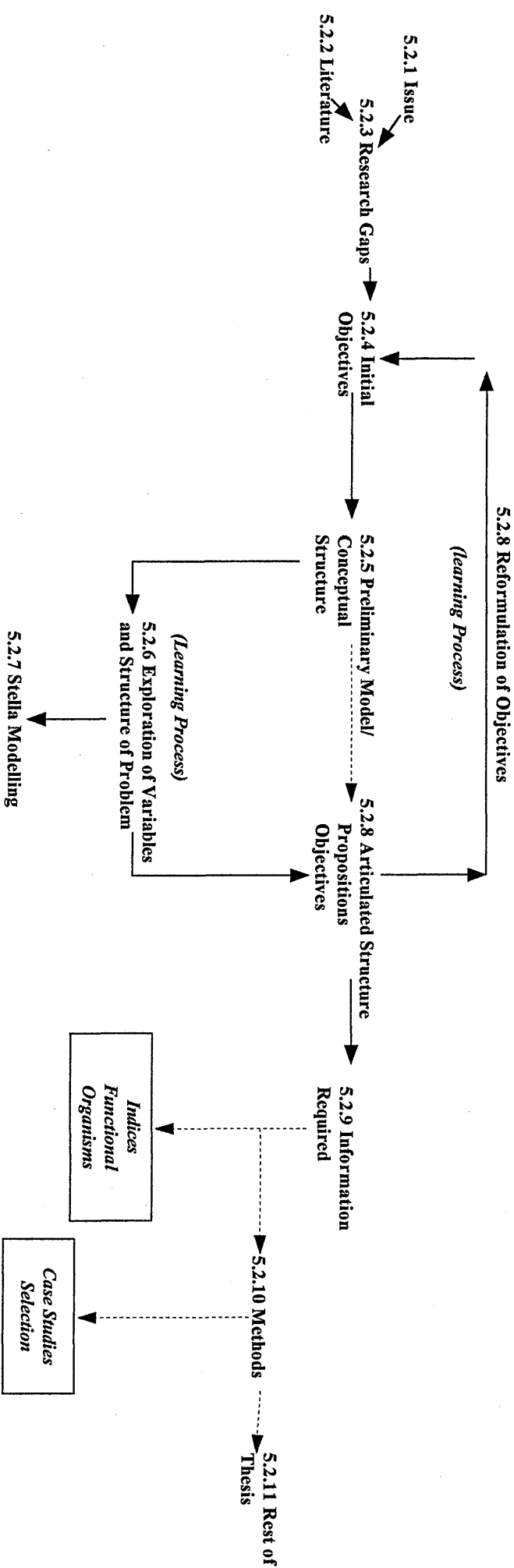
The issue which has emerged as central to this research is the way in which humans culturally perceive themselves as separate from their natural environment and how this cultural evolution affects the way 'natural' systems are studied generally. Human activity is either removed completely from the ecological equation or a completely anthropocentric approach is taken. In addition, the way in which 'nature' acts upon human society/culture is also generally neglected when urban/social models of human activity are being investigated. A key example of this is the way that treatment processes at water treatment works are generally regarded as separate from the treatment processes of water in 'natural' watercourses and the aquatic ecologies endogenous to them.

“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)” (Browne, Seaton, Jeffrey 1999, 2000).

In order to take cognisance of this issue the research has taken an interdisciplinary, ecotechnological approach toward the assessment of ecologically engineered water treatment systems. This research of ecologically engineered systems for wastewater treatment is used as a model of an ecotechnological, interdisciplinary approach to studying 'natural' systems generally.

Such an assessment can only be made if the self-purification (Guterstam, 1995, Mitsch and Jorgensen, 1988) capacity (Section 3.1) of aquatic systems generally, as a socially directed biophysical phenomenon, can be defined.

Fig. 5.1 The Research Design Process



5.2.2 Literature

This issue-based research necessitated an interdisciplinary approach (Chapter 2) and therefore the use of literature taken from more than one field of expertise.

The literature required to explore this issue was taken from both scientific and social science disciplines and from work which attempts to bridge the gap between these. The following table 5.1 details this.

Table 5.1 Types of Literature Used (some of which relate to more than one category)

Literature Type	Subject Examples
1. 'Scientific'	Aquatic Ecology; Population Ecology, Wastewater Treatment; Traditional and Alternative Wastewater Treatment Technologies, Aquaculture, Wastewater-fed Aquaculture, Ecological Engineering, Species Diversity and Classification, Taxonomic Nomenclature, Wetlands, Freshwater Pollution, Limnology, Environmental science, Food webs and Trophic levels, Biochemistry, Biomonitoring, Environmental Engineering, Water Quality Parameters.
2. 'Bridging the Gap'	Interdisciplinarity, Taxonomy, Knowledge Transfer, Ecotechnology, General Systems, Complexity and Self-Organization, Hierarchy, Emergence, Mapping, Knowledge Transfer and Translation, Science and Technology, Epistemology and Technology.
3. 'Social Systems/Non 'Scientific'	Ecotechnology, Emergence, Philosophy of Biology, Hierarchy, Human Organization/Ecology, Mapping, Sustainability and Sustainable Systems, Technology and Technological Evolution, Nature and Natural systems, General Systems Theory, Stability and Diversity, Self-Organization, Social Systems, Innovation and Technology, Knowledge Transfer and Translation, Epistemology.

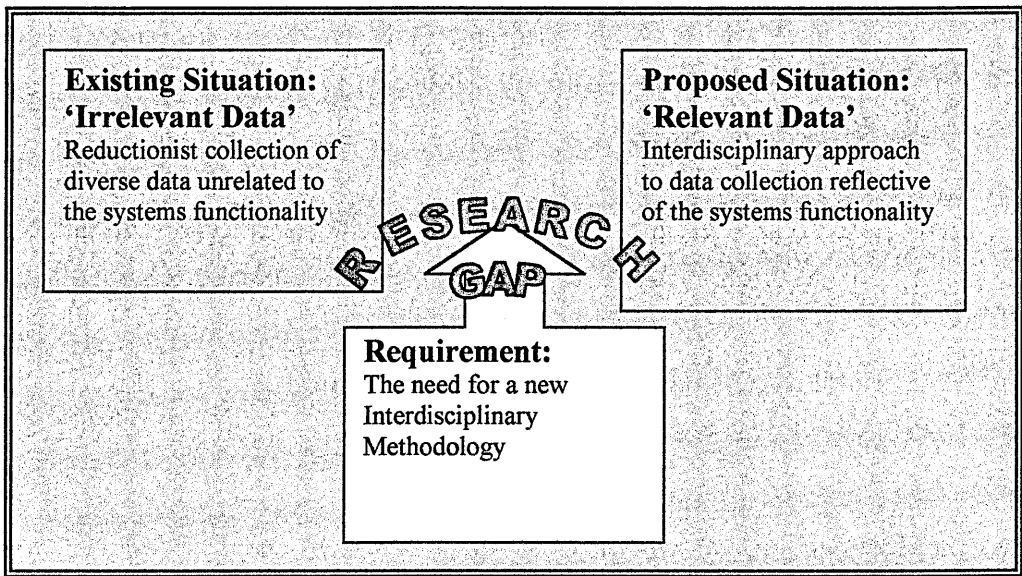
The diversity of literature types reflects the need to take an holistic approach to such issue driven research. The overlap between these serves to illustrate the ambiguity accompanying the 'sciences' and 'social sciences' distinction. Key examples from the extensive literature sources can be found in the Reference Section of this thesis.

5.2.3 Research Gaps

The research issue unearthed that there was no practical way in which to take an interdisciplinary, ecotechnological approach to investigating the functionality of such ecologically engineered systems for 'natural' water treatment. This was because data sets relevant to such an assessment were unavailable (Section 5.2.9). The need to assess how effectively ecologically engineered systems, as more 'natural' systems, can operate within the social framework of wastewater treatment highlighted certain methodological requirements which are central to such issue-based, and thus interdisciplinary, research generally.

Working with the resources available the following feasible research gap was identified, see fig 5.2 on the next page;

Fig 5.2 Locating the Research Gap



The use of ‘system’ in Figure 5.2 refers to ecologically engineered water treatment systems but it applies as an epistemological statement for ecotechnological, interdisciplinary investigation generally.

It emerged that the ‘new interdisciplinary methodology’ required was taxonomic and related to a need to map data described by different disciplines, biochemistry, biology and ecology. Subsequently it was the traditional classification systems that were integrated in order to map this data.

The ‘new interdisciplinary methodology’ as the workable research gap gave rise to the idea of using new taxonomic structures depending on the research issue.

5.2.4 Initial Objectives

The following objective was the predecessor to the objectives upon which this thesis is centred. This preliminary objective was required (as a focus) in order to identify the Research Gap detailed in the previous section.

Preliminary Objective:

To develop a technology assessment method for ecologically engineering systems in the context of urban water supplies.

The Preliminary Research Questions which were developed in light of this Objective were:

1.	What functional niche could ecologically engineered systems fulfil with respect to the storage, treatment and transport of water and at what scales could such (sub) systems operate within the urban regional system?
2.	What are the attributes (engineering, economic and social) of such ecologically engineered systems?
3.	What are the appropriate mixes and configurations of viable ecologically engineered water treatment systems that can be incorporated with conventional technologies to provide a framework for more sustainable water treatment?

That is to devise a method with which to investigate the potential of using “natural”, ecologically engineered water systems to biologically treat wastewater within/alongside the conventional regional urban water treatment framework existing and evolving in the UK.

It was when approaching this from a scientific perspective that the lack of relevant data (Figure 5.2) was realised. Although work on ecologically engineered systems for wastewater treatment had been documented as had work on traditional urban wastewater treatment systems, the details of the organisms, the ecologies (biocoenoses) which comprised them was rarely noted and when it was then it was generally not related, in detail to the performance data of the treatment plants. The systems, both traditional and ecologically engineered appeared too complex in ecological, biophysical, physiochemical and biochemical terms to be studies using traditional monitoring techniques. The criteria was not purely a traditional ‘green’ one relating instead to issues of sustainability. It became apparent therefore that before any such assessment could be made it was necessary to decide:

- ◆ What type of data was required
- ◆ In what way this data should be catalogued

The type of data required was of a biochemical, biological and an ecological nature that is

- ◆ Water quality
- ◆ Organisms present in the water
- ◆ Interrelationships of the organisms both with one another and their environment.

By simply listing the organisms present alongside the performance data it was very difficult to see treatment patterns bearing in mind that works vary in physical characteristics e.g. size and climatic character.

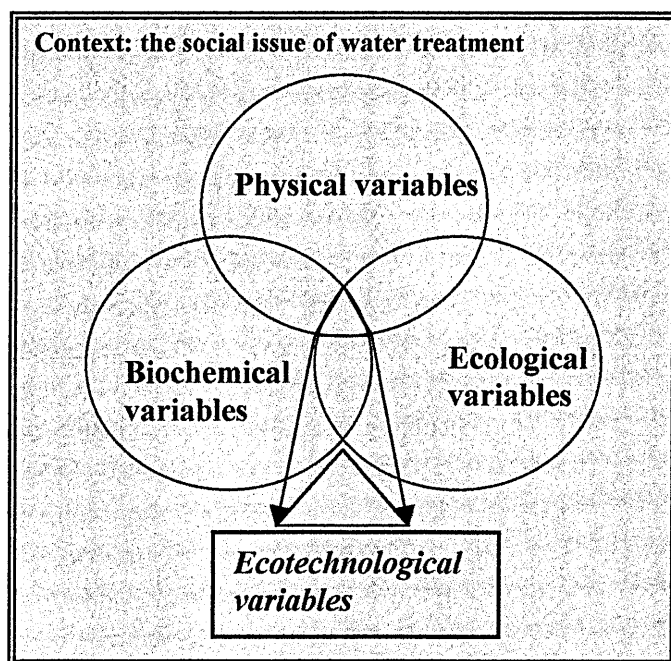
The idea was therefore to produce a framework, of some description, which enabled a systems relevant component; subsystem interrelationships to be described in a way meaningful to the issue (irrespective of geographical location etc.). Clearly in addition to practical barriers of collecting holistic data there is an epistemological problem of the way in which researchers are programmed by their disciplines and the boundaries between other specialist areas.

The Preliminary Objectives metamorphosed to accommodate this requirement and this is detailed in Section 5.2.8 of this chapter.

5.2.5 Preliminary Model/Conceptual Structure

To meet with the initial objective would necessitate the investigation of particular physical, biochemical and ecological (as defined by the disciplines describing them) variables associated with the social issue of water quality and its treatment.

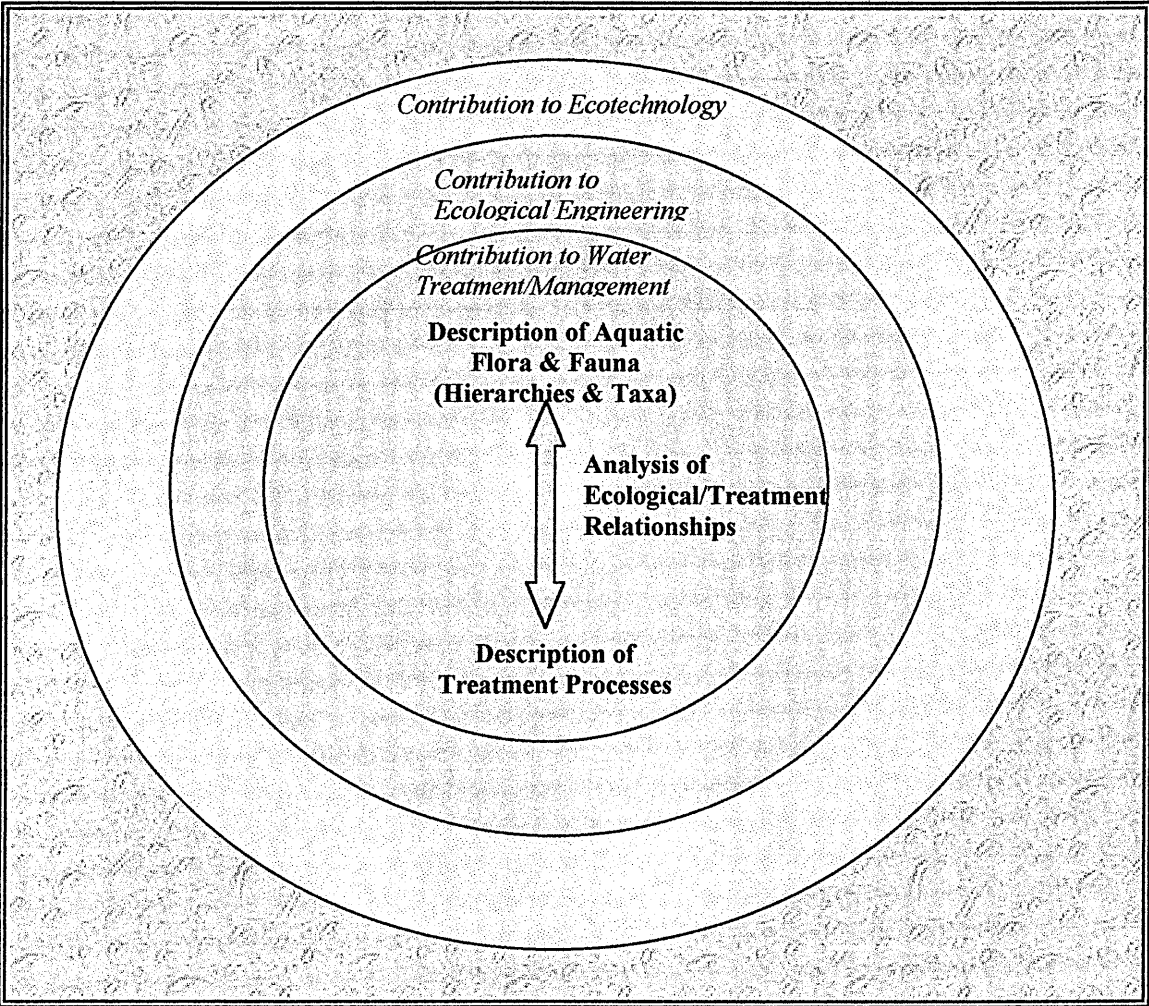
Fig 5.3 Locating the Variables for the Preliminary Conceptual Model



The preliminary conceptual framework for this research attempted to locate key mapping functions between water treatment processes and the classification of the aquatic organisms integral to these processes.

It was felt that such a mapping exercise would contribute not only to water treatment management but also to ecological engineering and subsequently via the process of interdisciplinary knowledge transfer ecotechnology

Fig 5.4 The Preliminary Conceptual Framework



Although the original conceptual framework encapsulated all the relevant aspects of the research it was changed to focus primarily upon the interdisciplinary requirement and the substantive research issue of mapping between biochemical, biological and ecological systems and the disciplines describing them (Fig 1.3). Before the reformulated, articulated conceptual structure is described (Section 5.2.8) the next section describes the decision process that led to that change.

5.2.6 Exploration of the Variables and Structure of the Problem: The Learning Process

Initially many variables were investigated in order to develop an assessment method for ecologically engineered water treatment systems. These variables can be divided into those which are generally dealt with by scientific and social science disciplines. The complexity of this exercise is illustrated in the following table:

Table 5.2 Exploration of Variables

SOCIAL SCIENCE VARIABLES	SCIENTIFIC VARIABLES
Development of Interdisciplinary Research Methods Economies of Scale Water Company Procedures Treatment Requirements/Standards Legislatory Restrictions and Bodies: Environment Agency (EA) (formally National Rivers Authority (NRA) stipulations Public Health Considerations Environmental Considerations Public Expectations and Demands Public Perceptions Aesthetics Policy and Law Jurisdictions Leisure Industry e.g Angling and Boating Training of Plant employees System Management Epistemological Technological	Water Quality Monitoring: <u>Chemical and Biochemical Variables:</u> Biochemical Oxygen Demand (BOD) Chemical Oxygen Demand (COD) Dissolve Oxygen (DO) Suspended Solids (SS) Ammonia Phosphates Nitrates Colloidal Activated Sludge Trace Elements Other Contaminants such as PCB's, Hormones etc. <u>Physical Variables:</u> System Location Climate; precipitation, light, etc System Size/Hydraulic regime System Topography <u>Technological Variables:</u> Sludge Transportation Machinery; aerators, filters, biofilters, trickle filters, growth medium, rotating biological contactors <u>Biological and Ecological Variables:</u> Type of Organisms Present Physiology of Organisms Number of Organisms Abundance of Organisms Turnover Rates Detritus Evotranspiration Biomass Effects upon Organisms and their Communities Microbial Cultures Bacteria Anaerobic/ Aerobic Aquatic Ecologies/Biocoenoses Herbivores, Carnivores, Detritivores Food Chains/Webs Biomonitoring

The table above is not totally reflective of the complexity involved. Coming from a scientific background it is notable that the exploration of variables associated more with those described by scientific disciplines and a 'bottom-up approach' to the research was favoured (section 1.5). Even within this research bias the level of complexity is somewhat understated. If, for instance, just Biological variables are taken then further complexity is unearthed as shown in the following Table 5.3 on the next page.

Table 5.3 Variables Within Variables e.g. Biological Variables

BIOLOGICAL VARIABLES	BIOLOGICAL VARIABLES (cont.)
<u>Primary Production</u> Phytoplankton production/growing season - Surface cover/shading (KJ m ⁻²) Phytoplankton production/growing seasons - Density (KJ m ⁻³) Phytoplankton Biomass - growing season mean (KJ m ⁻²) Phytoplankton chlorophyll α - growing season mean (mg m ⁻²) Phytoplankton P/B ratio.(turnover rate) Phytoplankton production/ chlorophyll α (KJ mg chl. α ⁻¹) Phytoplankton photosynthetic efficiency	Herbivorous fish production/growing season (Kg m Herbivorous fish P/B Herbivorous fish efficiency
<u>Secondary Production/Primary Consumers</u>	<u>Secondary Consumers</u>
<u>Suspended Fauna</u> Herbivorous zooplankton (types life stage etc) biomass (KJ m ⁻²) Herbivorous zooplankton production/growing season (KJ m ⁻²) Herbivorous zooplankton P/B Herbivorous zooplankton efficiency.	<u>Suspended Fauna</u> Carnivorous zooplankton (types, life stage etc) biomass (KJ m ⁻²) Carnivorous zooplankton production/growing season (KJ m ⁻²) Carnivorous zooplankton P/B Carnivorous zooplankton efficiency
<u>Benthic/Benthos Fauna</u> Herbivorous benthos (type, life stage etc) biomass (KJ m ⁻²) Herbivorous benthos production/growing season (KJ m ⁻²) Herbivorous benthos P/B Herbivorous benthos efficiency	<u>Benthic/Benthos Fauna</u> Carnivorous benthos (types, life stage etc) biomass (KJ m ⁻²) Carnivorous benthos production/growing season (KJ m ⁻²) Carnivorous benthos P/B Carnivorous benthos efficiency
<u>Herbivorous Non-Planktonic Fauna</u> Herbivorous macro- crustacea (types, life stage etc) biomass (Kg m ³) Herbivorous macro-crustacea production/growing season (Kg m ³) Herbivorous macro-crustacea P/B Herbivorous macro-crustacea efficiency Herbivorous molluscs (types, life stage etc) biomass (Kg m ³) Herbivorous molluscs production/growing season (Kg m ³) Herbivorous molluscs P/B Herbivorous molluscs efficiency	<u>Carnivorous Non-Planktonic Fauna</u> Carnivorous macro- crustacea (types, life stage etc) biomass (Kg m ³) Carnivorous macro-crustacea production/growing season (Kg m ³) Carnivorous macro-crustacea P/B Carnivorous macro-crustacea efficiency Carnivorous molluscs (types, life stage etc) biomass (Kg m ³) Carnivorous molluscs production/growing season (Kg m ³) Carnivorous molluscs P/B Carnivorous molluscs efficiency
<u>Herbivorous Fish Fauna</u> Herbivorous fish (types, life stage etc) biomass (Kg m ³)	<u>Carnivorous Fish Fauna</u> Carnivorous fish (types,life stage etc) biomass (Kg m ³) Carnivorous fish production/growing season (Kg m ³) Carnivorous fish P/B Carnivorous fish efficiency
	(S,HRT,Depth,SA/V,Temp,Light,pH,Alkalinity,primary production*,primary consumption*,secondary consumption*)

Complexity is related to the scale of the assessment. To produce any sort of realistic issue-based assessment would mean incorporating at least all the above into some sort of model. This was felt to be beyond the means of the research which was reliant upon secondary data. Several different avenues were explored when attempting to use multifarious data the following Flow Diagram (Figure 5.5) illustrates this exploration and reveals the choices which were taken:

Fig 5.5 The Research Design Decision Flow Diagram

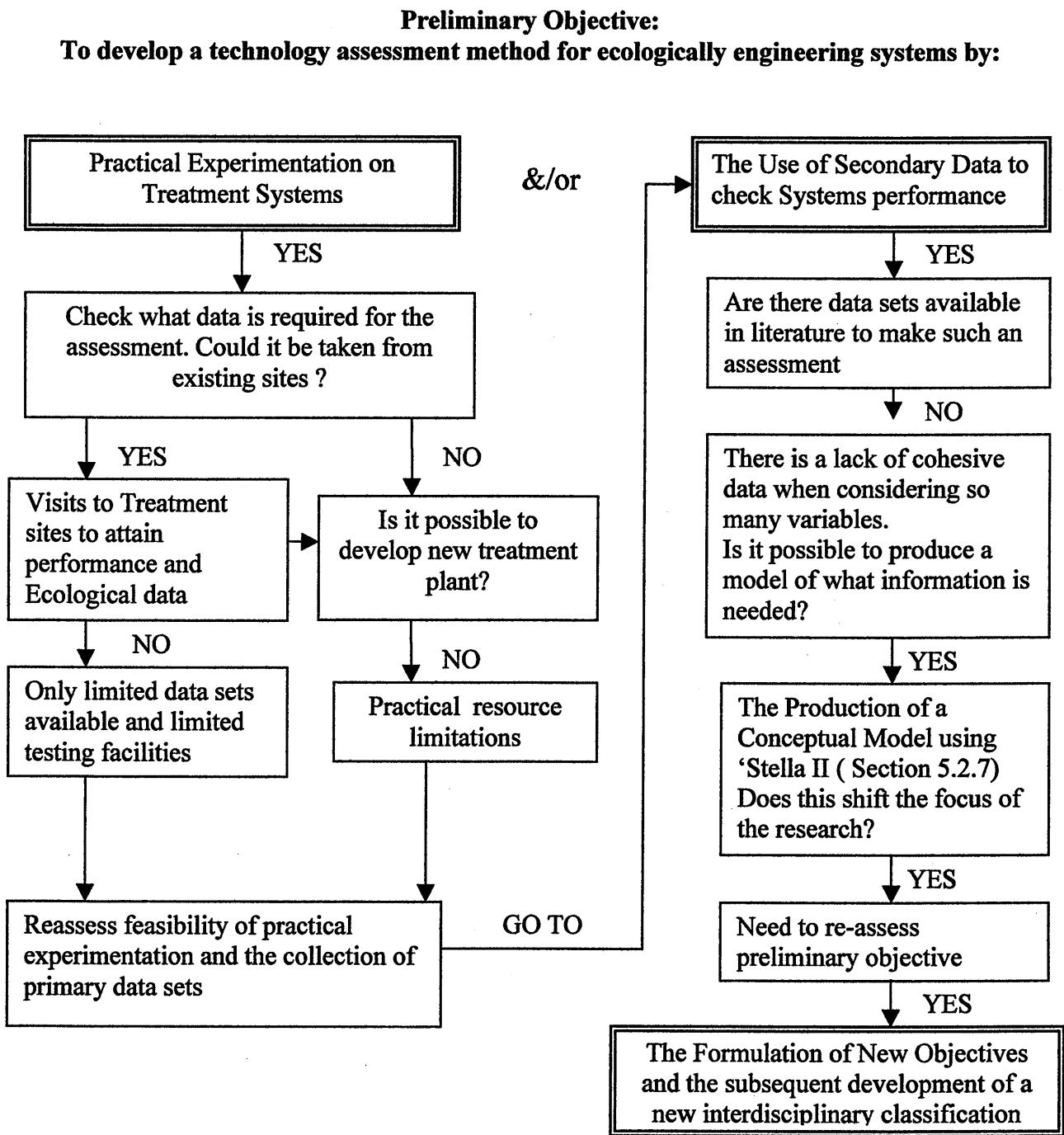


Figure 5.5 illustrates the decisions which were made during the research and its design which lead to the reformulation of the research objectives (Section 5.2.8). This decision process was key to the development of the research which consequently evolved into the articulated structure detailed in section 5.2.8 and onwards. Further research decisions are detailed in Section 5.2.9 and 5.2.10 of this chapter.

It was obvious from the exploration of secondary data that there was a lack of an interdisciplinary framework with which to integrate and assess the functionality of variables. There appeared to be no formalised way of integrating variables within either the 'social sciences' or the 'sciences' let alone between them. Although human reason is constantly mapping between variables, every day life necessitates this, there appeared to be no formulised way in doing this when researching using secondary data or as an incentive for collecting primary data in the field. With this in mind it was first necessary to simplify the problem by choosing variables which were specifically relevant to the ecological engineering of wastewater treatment

The following Section describes the development of a conceptual model highlighting the variables which became integral to the novel research activities which formed the substantive.

5.2.7 The Conceptual Model – Stella Modelling

In order to simplify the complexity involved in ecological engineering water quality systems, four organizational levels were chosen. The first three would be represented by submodels within a whole conceptual model of water quality change. It was felt that a fourth sociological level was unnecessary as this was emergent from the other three. The sociological level has been identified here simply to illustrate that the submodels detailed are not operating in isolation from sociological issues such as public perception of water quality and treatment etc. The sociological aspect relevant to this research which emerges relates more to the epistemological issues of classification and the way in which perceptions of data can change. This has implications for studying the process of knowledge transfer in organizations (Chapter 10).

These four organizational levels are detailed in table 5.4 on the next page.

It is realized that the delineating of these organizational levels is artificial and not ontological as each one lies within i.e. is nested within, the next. The usefulness of such a hierarchy is that it defines the distinct knowledge domains and classification systems required in order to facilitate a holistic perception of the system.

These levels were used in the construction of a conceptual model using the 'Stella II'* (Paterson and Richmond, 1994) conceptual modeling package (Fig. 5.10). The following describes how this was done. Ideas from this conceptual modeling activity are revisited in Chapter 8.

Table 5.4 The Four Organizational Levels Central to Water Quality Change Systems

Organizational Level	Description of Level
Level 1 ~	The Physico-biochemical level which can be termed the lowest organizational level and also the research context driver is defined by the biochemical aspects of water quality. In this case the concentration of the biochemical oxygen demand, dissolved oxygen and suspended solids (although the latter borders on the biological level of organization). It could equally well apply to other biochemical systems.
Level 2 ~	The biological level of organization pertains to detailing the functioning of organisms within a system as separate individuals.
Level 3 ~	The ecological level of organization, this defines the relevant functional interactions between the individuals defined by biological levels.
Level 4 ~	The sociological level includes some human factor. In this context it actually produces the lowest organizational level i.e. the biochemistry of the whole system.

Obviously the myriad of complexity described in tables 5.2 and 5.3 requires simplification. This was achieved by choosing key physical, biochemical and ecological parameters within the research issue. These were then used to form a conceptual model which integrates the key physical, biochemical and ecological parameters chosen.

◆ The Physical Mapping Sector

The physical mapping sector actually centres round what could be perceived as a qualitative term i.e. “water quality”, however water quality is an identifiable parameter as is “water treatment”. Both terms have wide ranging implications and are prone to rather subjective use, but as parameters, they can be measured as long as there exists a calibrating criterion. Such a criterion can be generated by relating the physical aspects of space and time to the ecological and social environment.

Traditional modelling of water quality tends to use a mass balance approach to incorporating the physicochemical changes i.e.

Rate of accumulation of mass component in the system

=

Mass flow of the component into the system

-

Mass flow of the component out of the system

+

Rate of production of the component by the reaction.

This can be simply represented as

(Accumulation) = (In) – (Out) + (Production)

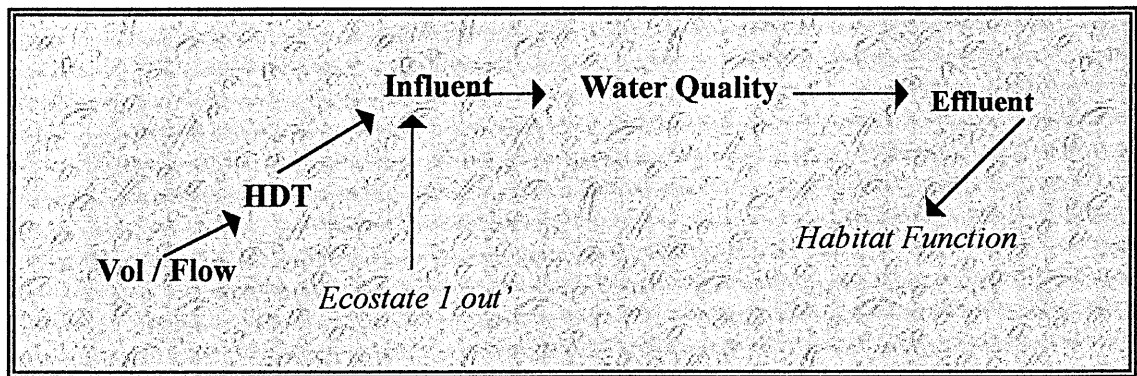
This approach is fine when physico-chemical parameters direct and encapsulate the model as a whole but it does not work when the system modelled is made up from the several submodels each with differing mass balance agendas, but all pertaining to the resulting water treatment and water quality changes.

The mass balance approach was not used in the conceptual model. Instead water quality is regarded as being primarily influenced by the time water remains within the physical system. The physical mapping sector consists simply of a water quality stock flanked by the simple flows represented as ‘influent’ and ‘effluent’. These are deliberately left ambiguous as they are central to the integration of all the model subsystems and are subject to, and in effect created by, the model as a whole. This mapping sector is the only one which does not contain a submodel. This is because it is created by all the others acting in time and space and thus the one definitive converter which feeds into this physical sector is hydraulic detention time (HDT) which is a measure of how long water remains in a system. In water treatment systems the hydraulic detention time is dependant upon the treatment requirement of that system, which is traditionally driven by the effluent biochemical oxygen demand (BOD) that is deemed acceptable.

Hydraulic detention time is a function of volume (V) and flow (Q).

Figure 5.6 below, presents a schematic representation of this.

Fig 5.6 The Physical Mapping Sector -A Schematic Representation



**Italicized components represent links to other parts of the conceptual model.*

◆ The Ecostate Mapping Sector

This sector presents an extension to the physical system modelling environment by incorporating a water quality change hierarchy comprised of three of the four organizational levels detailed in Table 5.4, each level comprises separate submodels; ‘Biochemical,’ ‘Biological’ and ‘Ecological’ and ‘sociological’. The following sections i), ii), iii), iv) detail these.

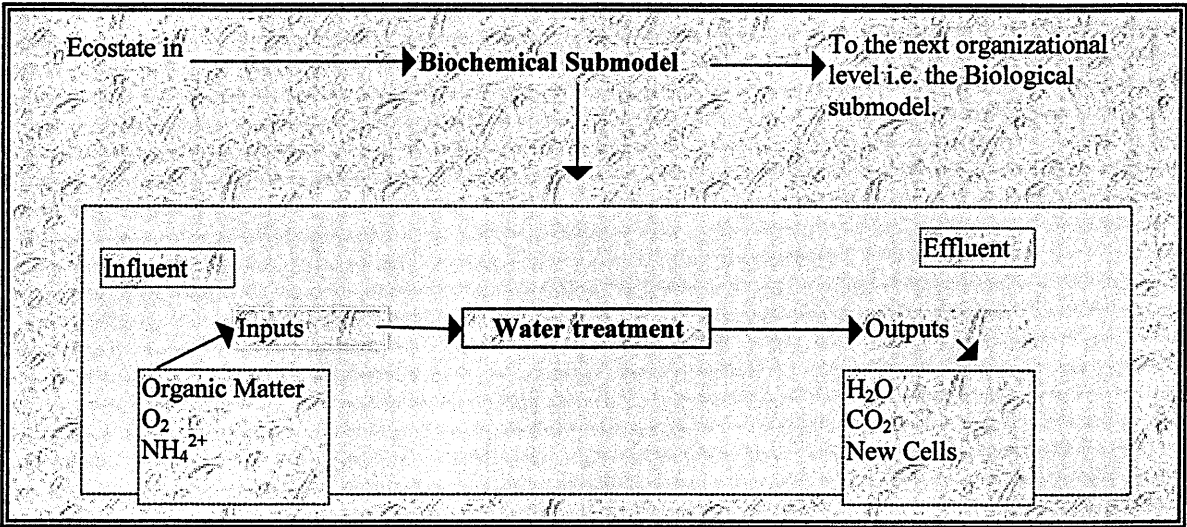
i) The Biochemical Submodel

This submodel actually encapsulates the organizational transition between chemistry and biology as it is here that the chemistry of the water dictates cellular development (Section 3.2). As a state it resembles the traditional “biological” treatment which occurs in water treatment works. The occurrence of organisms in such systems is limited mostly to simple prokaryote* forms e.g. bacteria although some higher eukaryote* organisms, such as fungi, rotifers and nematode worms may also be present (although their functionality in the treatment process is generally not given any consideration compared to prokaryote bacteriological activity).

The term ‘Biochemical’ was chosen here to distinguish from the organizational levels which represent the interaction of organisms, other than microbes, with their environment and one another. The biochemical state is intrinsic to all the other organisational levels detailed. It represents the terminal level of organization perceived in the treatment of wastewater but is actually just one point in a water treatment loop (Fig.3.1) where all points are mutually dependant.

Figure 5.7, below, presents a schematic representation of this.

Fig 5.7 A Schematic Representation – The Biochemical Submodel (Ecostate Mapping Sector)



This Biochemical sub-model uses the simplified universal description of wastewater treatment.



This function represents the conversion of soluble organic matter into insoluble microbial cells via the process of mineralization (section 3.2) and thus the stabilization of organic matter. Biomass can be more easily separated from the water than dissolved and suspended organics. This level is relevant to the situation within water treatment works and to the release of sewage and the subsequent fertilization of natural waterways. It does not represent, however, the total potential for water quality change within a 'natural' water body, this can only be realised when higher ecological organizational levels are incorporated.

The flow from the biochemical submodel to the biological submodel is termed 'Biochemical Tolerance', this is intrinsically determined by the outputs of the Biochemical submodel. It represents the dissolved oxygen* (DO), biochemical oxygen demand* (BOD), suspended solid* levels (SS), nitrate and phosphate concentrations which are encountered by the aquatic organisms and thus dictates the organisms which can act within such a system. This thesis concentrates predominately upon those physico/chemical parameters (BOD, DO and SS) which relate to the design of traditional wastewater treatment facilities for the prevention of organically loading 'natural' watercourses. Advanced treatment processes are used to remove phosphates and nitrates from the water, although these can also be reduced by ecologically engineered systems particularly those which use autotrophism* primary production (plant species).

ii) The Biological Submodel

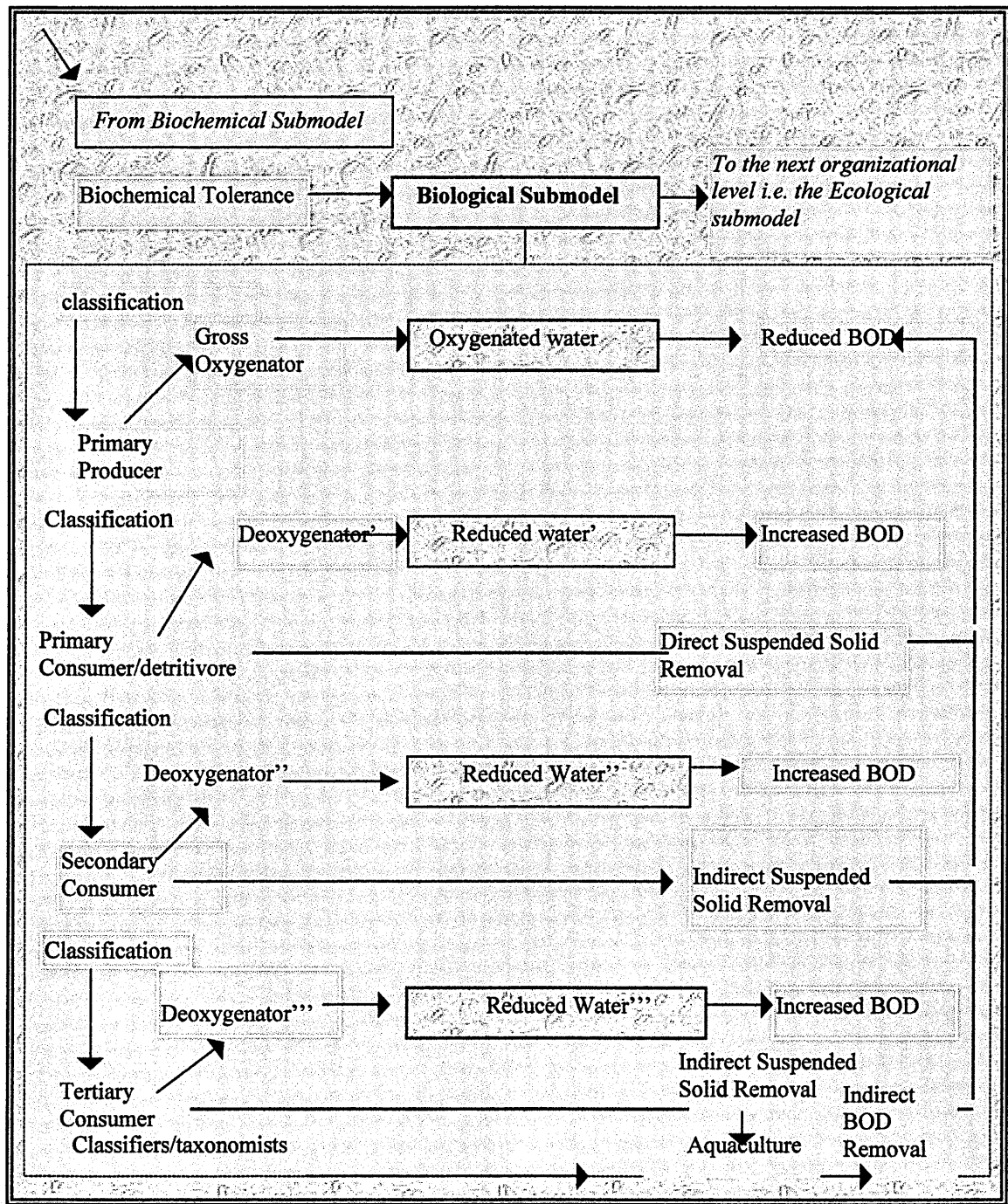
The biological submodel simplifies organism types by classing them with relation to their relevant gross functions in changing the water quality in terms of the parameters defined earlier, i.e. (BOD, DO, SS). For further specific purposes, say the restocking of a system, other traditional taxonomies can be used e.g. the Linnaean classification (Chapter 6).

(It should be noted that the term BOD is used to represent biochemical oxygen demand as opposed to BOD₅. This is because the rationale behind the standard BOD₅ test procedure is the laboratory simulation of the self-cleaning process of British rivers and it is presumed that all rivers in the UK reach the sea in less than five days. The test is also carried out at 20°C because UK river temperatures never exceeds this. BOD₅ is not a suitable global test and so the generic term BOD is used in this research. Dissolved oxygen (DO) levels are inversely related to the level of BOD (Figure 3.2).

The flow which enters the highest organizational level of this Ecostate Mapping sector (i.e. the ecological subsystem) is named "Biological Tolerance". This dictates the biological constraints upon the aquatic ecologies i.e. relates to which organisms are adapted to survival within fertilized fresh waters. This level is related to the Saprobic (Saprobien) system which is a bioindicator* classification scheme and is detailed in Tables 6.5 and 8.4. This level can also be directed by the social system where humans act as designers and caretakers of ecological systems.

Figure 5.8,presents a schematic representation of this.

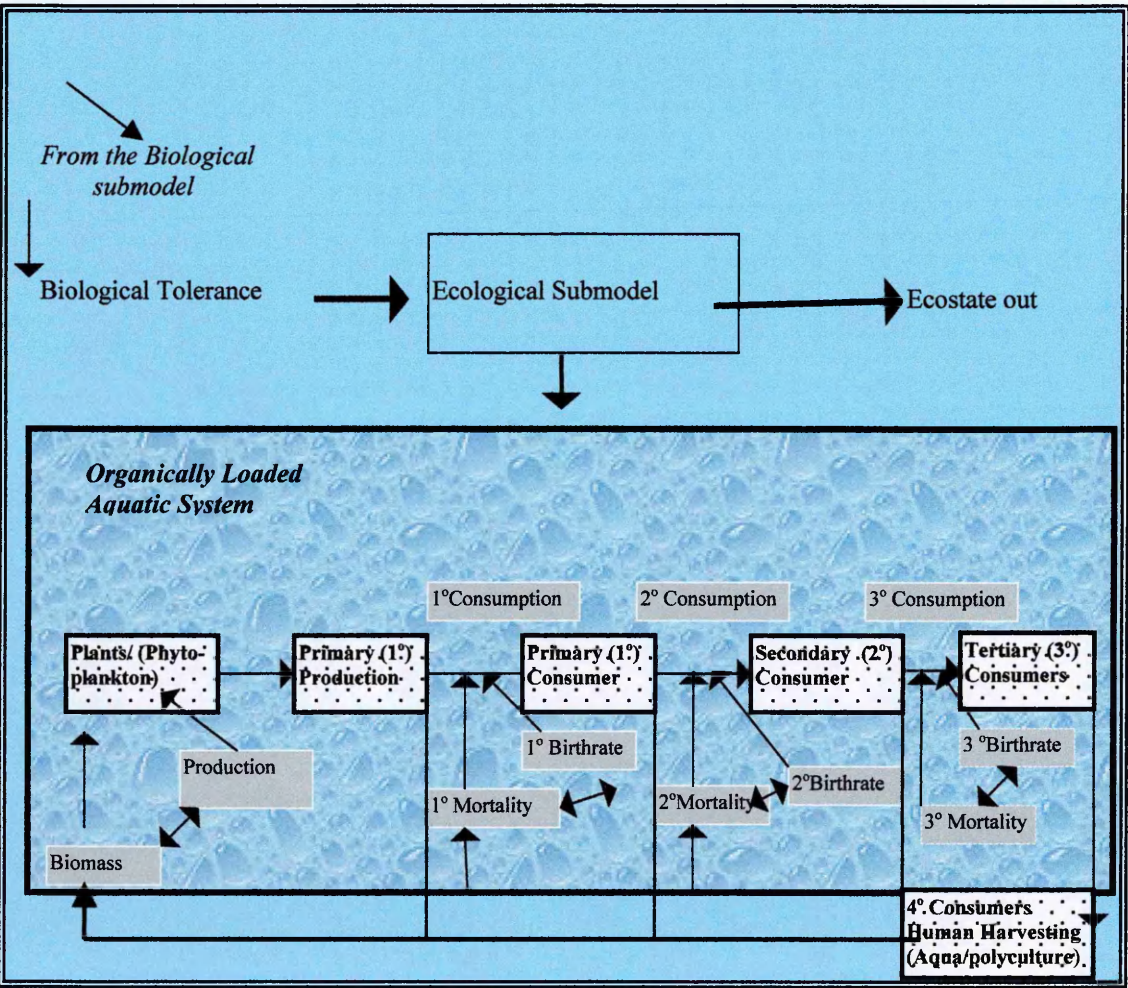
Fig 5.8 A Schematic Representation – The Biological Submodel (Ecostate Mapping Sector)



iii) *The Ecological Submodel*

Fig.5.9 A Schematic Representation- The Ecological Submodel (Ecostate Mapping Sector)

The Ecological submodel, below, contains four in-system trophic levels i.e. primary producers, primary consumers, secondary consumers and tertiary consumers but a food chain of any length could have been used.



The human component could be treated as a further fifth ‘trophic’ level (see Chapter 7) external to the physical system. The plant (producer), primary, secondary and tertiary consumer flows dictate (generally via consumption) the levels of each trophic level stock* and these are in turn are dictated by the birth rate minus the mortality rate. The biomass is multiplied by production in the case of primary productivity of plants.

The additive converters* (birth rates) and the reducing converters* (mortalities) of each trophic level are dictated by the consumption function of the next/higher consumption level. Human harvesting can be defined as the terminal consumption level but this does not equate only to the physical consumption of biomass but also equates to the human use of such 'natural' ecologically engineered systems as wastewater-fed aquaculture systems (Chapter 4).

A conceptual modeling software package, 'Stella II'* was used to illustrate the interconnectivity of the submodels (Figure 5.10). The complexity of data required to run such a model negated such compilation and illustrates the need to map between such subsystems and the knowledge domains which describe them. In this way the model provided not only a conceptual illustration of the research but also served to highlight the research gap (Section 5.2.3) intrinsic to such a piece of interdisciplinary research.

♦ Modelling the Organizational Levels of a Water Quality Change System

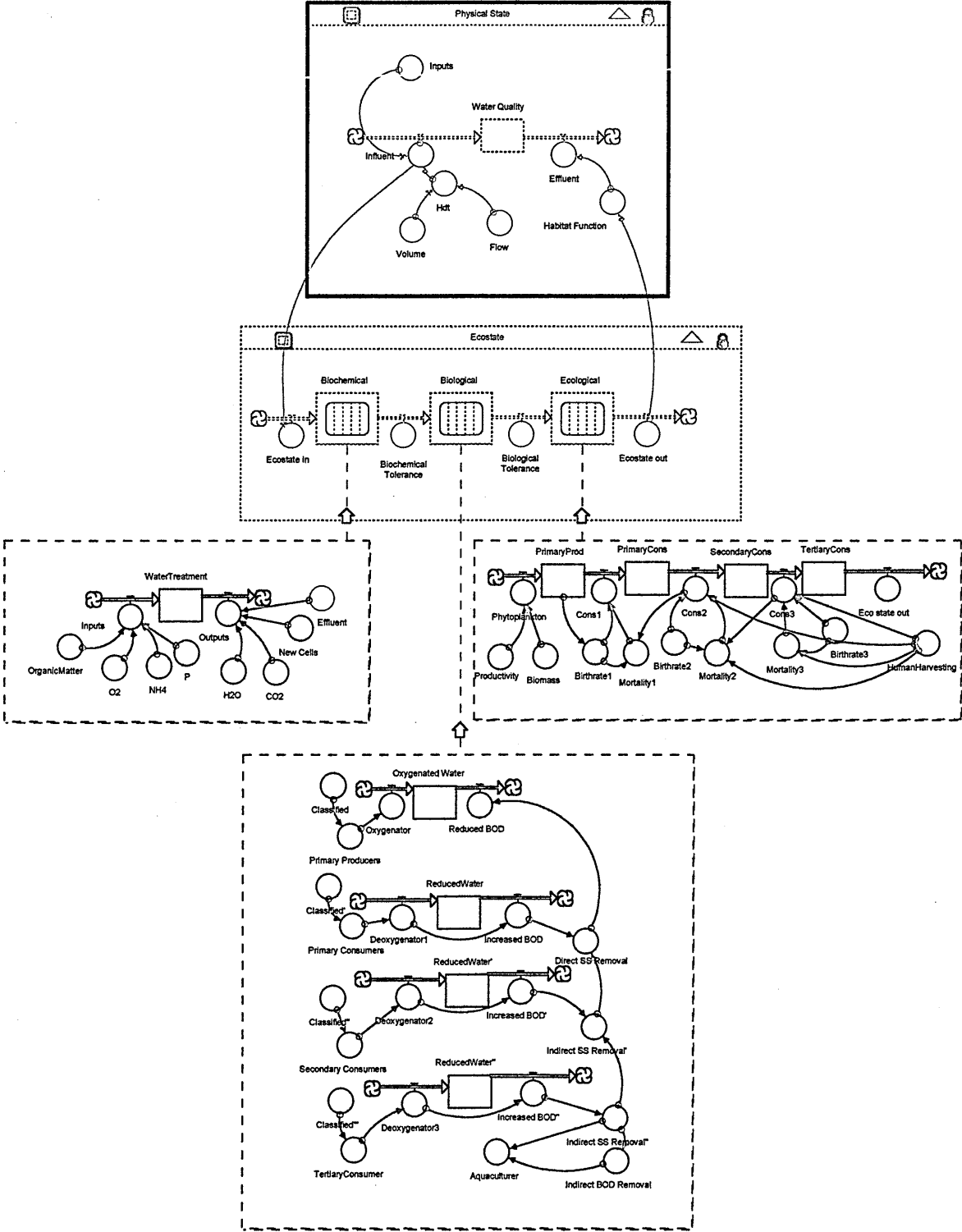
When all the organizational levels from the previous section are linked up they produce the conceptual model in Fig 5.10 which can be found on the next page. The concepts generated from this modelling activity are stated (5.2.8) and used in the substantive research detailed in the following sections and chapters.

(IV) The Social Mapping Sector – Physically Beyond the Realms of this Thesis

The third Mapping Sector contains the fourth sub-model and deals with the sociological aspects of the system (patterns of human consumption) it is connected to the ecostate sector via an ecostate flow which flows into the model. The factor central to all the consumption levels is the fertilization of water, whether this is within a treatment plant or a "natural" water body such as a river or lake. The fertilization of water is the fulcrum between the ecological engineering of water treatment and the development of aquatic ecologies which may or may not be farmed.

Modelling the sociological (social) organizational level is beyond the scope of this research. Instead this thesis broaches the sociology of the system via the emergence of a definition of "soft" technology (Chapters 1, 2 and 10) which enables an ecotechnological, ecological engineering approach to be taken whereby both the roles of humans and other organisms are considered as central to the development (engineering) of 'natural' systems.

Fig.5.10 The Whole Conceptual (Stella II) Model



5.2.8 The Articulated Structure: The Reformulation of Objectives

The non-linearity of this research process can be observed in Fig 5.1 and the reformulation of the Preliminary Objective can, together with the development of the Conceptual Model, Fig.5.10 be considered as the 'learning process' which is core to the research development.

From the Research Design Process described so far it is clear that the aspirations of the Preliminary Objective were over ambitious. Before such an assessment could be made consideration had to be given to create an interdisciplinary framework which could assist the collection and analysis of relevant data.

The Preliminary Objective:

To develop a technology assessment method for ecologically engineering systems in the context of urban water supplies.

metamorphosed to accommodate this requirement

1. To explore an ecotechnological, interdisciplinary approach to studying 'natural', in ecologically engineered terms, systems.

This can be split into two Sub-Objectives:

To develop an assessment method for investigating the bi-directionality between water quality (biochemical) and ecological change as a socially directed biophysical or 'natural' technology.

This second research objective led to the development of a third and final objective:

To develop a taxonomic framework (ecotaxonomy) which takes into account the concept of emergence in describing such 'natural' systems to allow for objective (interdisciplinary) classificatory adaptation according to the research focus.

From the conceptual model Fig 5.10 an important research activity was isolated, that of the mapping between the biochemical (abiotic) and ecological (biotic) organizations central to water quality change. The intermediate organizational level, which links the biochemistry and the ecology of the system, is obviously identifiable as the organisms (biological level) which exist in the system itself. Organisms can be defined differently depending upon the physical and perceptual hierarchies concerned (Figure 2.3).

Fig 5.11 on the next page illustrates the shift in research focus, in effect the elements are the same as in the original Fig. 5.4 but the approach has changed from one of scientific 'hard' analysis to investigating the way in which academic description can effect interdisciplinary research and in turn the way in which data is analysed.

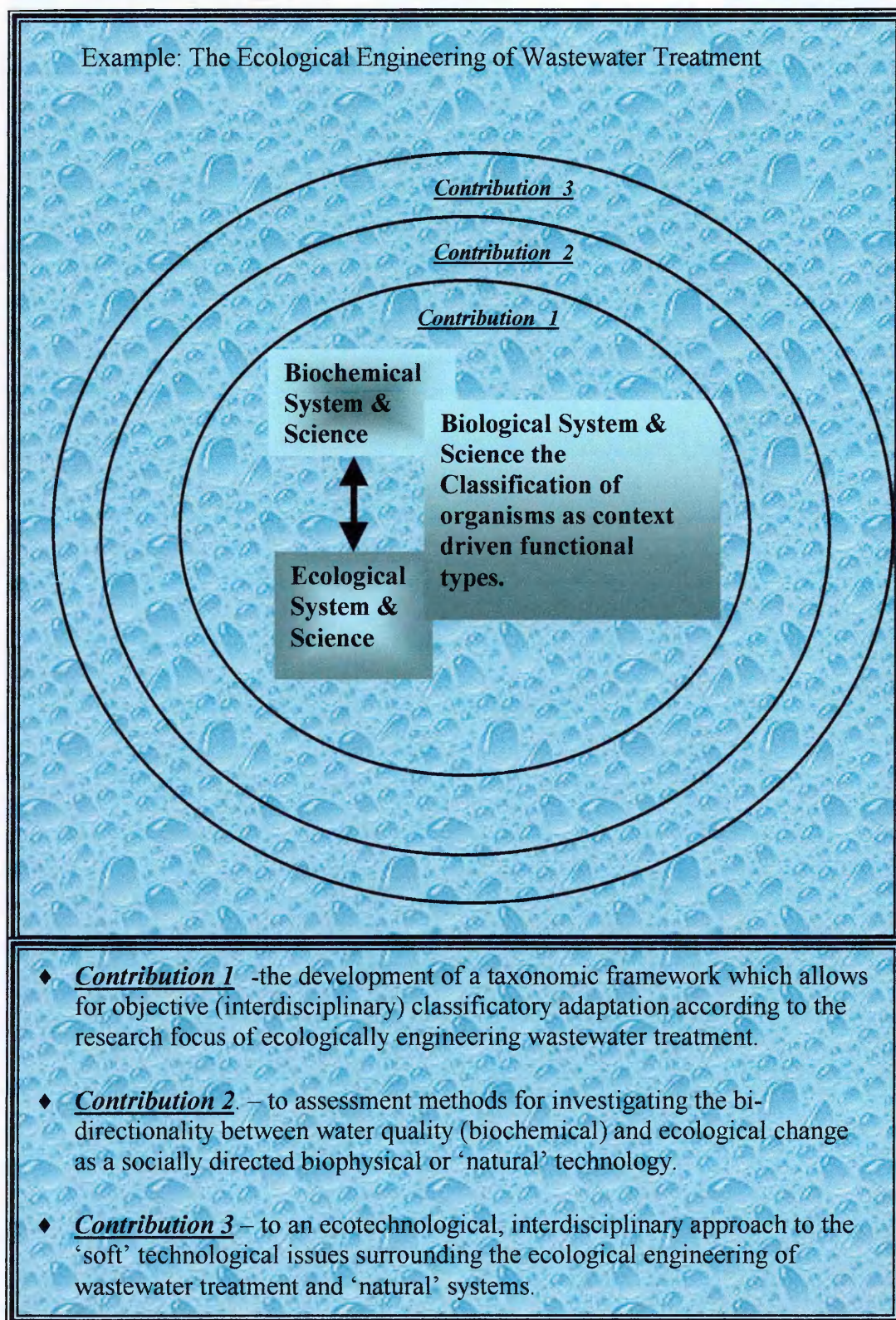
In support of such a 'soft' technological approach it should be noted that the developing discipline of ecological engineering has been and still continues to be, dominated with research of a 'hard' technical 'nature'. This was more than apparent at the last International Ecological Engineering Conference "*Managing the Wastewater Resource: Ecological Engineering for Wastewater Treatment* " (ÅS, Norway June 7-11th 1999) where the research still seemed to be very much site specific and left to the attention of chemical engineers. Despite this, the research detailed here was warmly received by the ecological engineering fraternity who expresses a genuine interest in taking a more ecotechnological approach and facilitated the publications from this work

The preliminary conceptual framework Fig 5.4 where the contribution to "water treatment management", "ecological engineering" and subsequently "ecotechnology" was firmly based within the concept of designed water treatment systems has, therefore, been extended to incorporate ideas regarding the general treatment of water both within treatment plants and 'natural' water courses.

The updated conceptual framework redefines the research as an exercise in classificatory mapping that investigates how changing the description of organisms can generate more useful analysis of data when describing such complex systems.

If organisms are classified in terms of their relevant biochemical and ecological function simultaneously then their potential as ecological engineers of water quality change systems may be realized. Obviously water quality change is an ambiguous, complex process and so two interrelated, pertinent, biochemical water quality changing parameters were chosen, to simplify and map the ecological functionality of the system. These are biochemical oxygen demand (BOD) and organic (as opposed to inert) suspended solids (SS) (Sections; 1.3.3, 3.3, 4.5.4, 5.2.7). These parameters are relevant to the organic loading of waters which occurs when 'sewage' is disposed of. They are relevant therefore to traditional water treatment, which use as a consent criteria, in addition to ammonia concentration, levels of works effluent BOD, and to the fertilization of aquatic systems, which occurs, for example, in wastewater fed aquaculture.

Fig 5.11 The Updated Conceptual Framework



In this way it is the functional classification of an organism's biology which acts as a facilitator to mapping (section 1.2.1) between the biochemical and the ecological states of a system and also the knowledge domains (biological science disciplines) which define them. This requires numerous exercises in reclassification (see Chapters 6,7,8,9 and Appendices).

5.2.9 Information Required

The data required to test out a new interdisciplinary, classificatory framework was different to that required for looking at the traditional treatment of water *per se*. Because an ecological engineering approach was being taken emphasis simply upon the physicochemical aspects of water quality change was shifted to the ecological relationship between the organisms existing in the biochemical environment.

To simplify this, the universal (in water quality monitoring terms), parameter of biochemical oxygen demand (BOD) was taken as the singular biochemical calibration of the systems water quality (Sections; 1.3.3, 3.3, 4.5.4, 5.2.7, 5.2.8).

Data needed to be taken from a system that detailed change in BOD alongside the documentation of ecological types (organisms) within the system. Unfortunately most case study documents on such water quality change and/or ecological systems did not provide comprehensive biological data. This situation reflected the tendency to identify and record only a few organisms in each system, namely, those which were felt, for whatever reason, to be of principal interest e.g. the principal stocking or produce organisms of a wastewater-fed aquaculture pond or the principle biomonitoring organisms in polluted waterways. This lack of data is further detailed in Chapter 6 with reference to the biological classification of data for ecological engineering.

This situation is reflective of the research gap detailed in Section 5.2.3 and validated the requirement to re-address the need for relevant data collection. To test whether this could be approached by changing the data collection and categorisation framework required finding a case-study that although not purposively reflective of an interdisciplinary study, did, by merit of its subject, generate a comprehensive, if not complete, ecological data set. There were relatively few of such studies to be found. This is unsurprising and encouraging considering the premise of this research

In the end only two water quality case studies in the literature survey were found to meet the ecological data criteria. Chapter 4 considered the Wastewater-fed Aquaculture or more specifically polyculture model as an example for this research and secondary data was taken from a case study of such a system. In addition, comprehensive data sets were discovered describing a relatively undisturbed lake system and these were used as a control to investigate the data sets of the wastewater-fed polyculture system (Chapter 9). These studies are identified in the next section (5.2.10) and further detailed in Chapter 9.

5.2.10 Method and Case-Studies Selection

The choice of Case Studies to access comprehensive biological data sets could form a continuum of Fig 5.5. The Research Design Flow Diagram, only now the emphasis is on the method of research as opposed to the design, this is illustrated in Fig. 5.12. on Page 87.

The data/ information from the chosen case-studies was catalogued and then reclassified according to the organisms relevant ecological engineering potential. This classifying of the organisms intrinsic to the water quality change systems required creating indices of functional organisms in terms of their water quality change potentials. The exercise used a simple new classification system or ecotaxonomy to do this.

The development of an ecotaxonomy to re-classify biological data for ecological engineering water quality change systems required the following information:

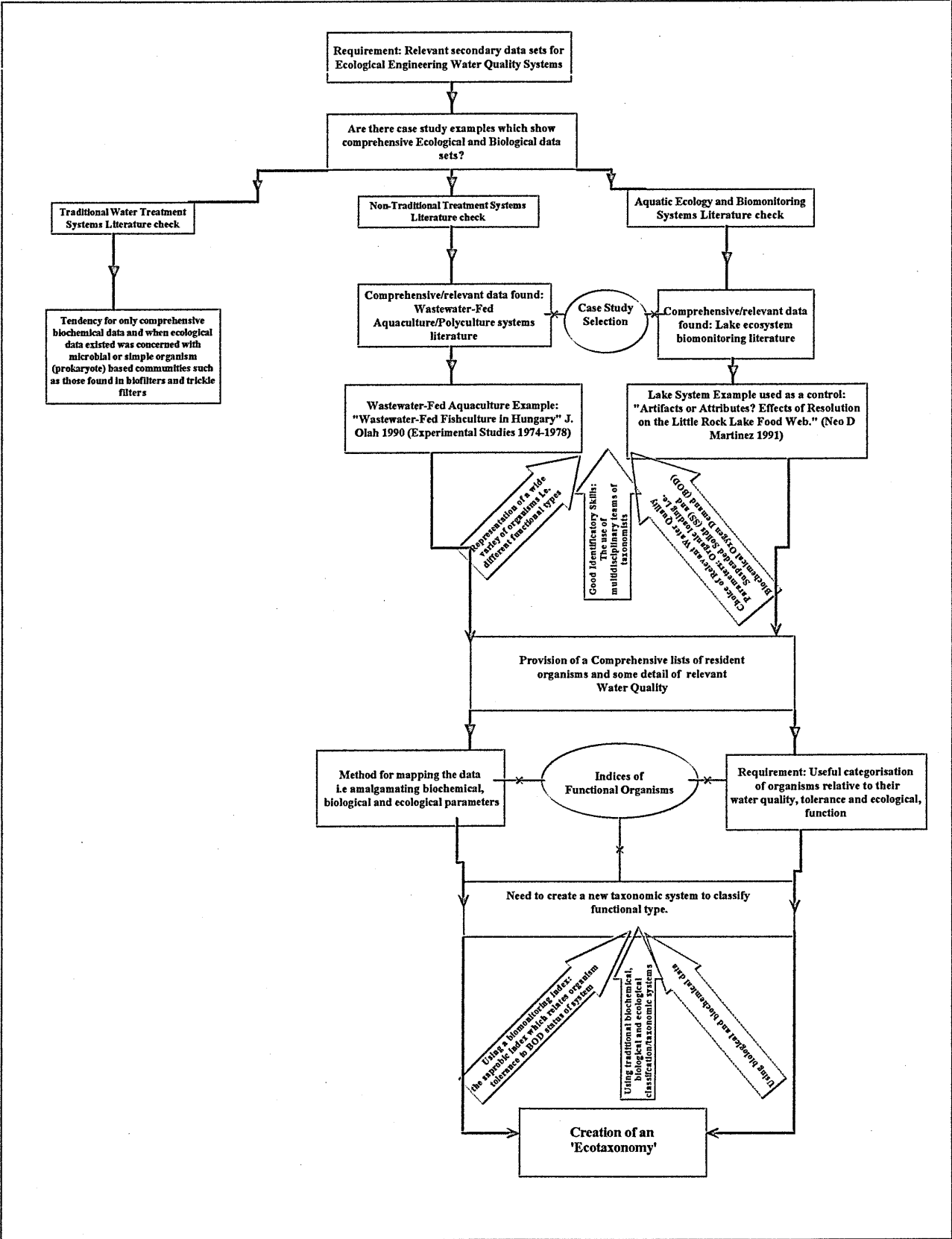
- ◆ Identification of the organism using traditional biological classification (Chapter 6)
- ◆ An indication of the organic (BOD) tolerance of the organism (Section 6.5.4)
- ◆ The ecological status of the organism in terms of the aquatic food-chain/web (Chapter 7)

Simple species listing were not sufficient for such an exercise. Each organism had to be studied to find out its tolerances to BOD change and its metabolic synthesising /nutritional habits at different times in its life cycle and how these impinged on the other organisms in the system.

This meant that data had to be correlated from a variety of different sources including biological , ecological, chemical, environmental and amateur naturalist journals and texts. It was rare for the information required to re-classify a single organism to be found from a singular literature source. This again highlighted the diffuse nature of biological investigation and the difficulty of using (biological and ecological) scientific data when studying such issue driven systems

The method used was to select the relevant case-studies and test out the ecotaxonomy using the data sets provided (Chapter 9). Although the re-classification exercise was relatively simple it required investigating each organism of the data set and was a lengthy procedure. Microsoft Access Databases were used to store and collate the data and the stages of re-classifying it.

Fig. 5.12 The Method Design Flow Diagram



5.2.11 Rest of Thesis

This chapter has detailed the research design process and thus has alluded to information found later in the thesis. The issues stated below are encountered in the subsequent chapters and relate generally to problems of classification when mapping between the (sub) disciplines which traditionally describe the parameters of the separate sub-models described in Section 5.2.7.

- ◆ Traditional biological classification (Chapter 6) is often unhelpful when attempting to define an organisms functional relationships with its surroundings. In this way traditional biological classification systems do not provide a useful framework for representing aquatic organisms in terms of their biological function upon water quality (or the effect of water quality upon their biological function) and the reasons for this are detailed in the following chapter.
- ◆ Traditional ecological theories and classification need to be incorporated when defining an organism's ecological engineering functionality. There is a need to define the interrelationship not only between water quality and organisms as individual components but also as organizations (ecologies/biocoenoses*) of them. The ecological tools which can contribute to redefining organisms in this way are described in Chapter 7.
- ◆ The integration of key classificatory concepts described in Chapters 6 and 7 contribute to the development of a new biological taxonomic system which, maps between the relevant biochemistry and ecology of the system. The development of this 'inter' taxonomy or 'ecotaxonomy' is detailed in Chapter 8 and is tested, using biological data from limnological* and aquaculture case studies, in Chapter 9.
- ◆ The relevance of this type of ecotaxonomic development to other research projects which require similar interdisciplinary approaches. The implications and limitations of such a method, in Chapter 10

Chapter 6.

Exploring Useful Biological Classification in the Context of Ecological Engineering Wastewater Treatment Systems

6.1 Introduction

*"The world is so full of a number of things
I'm sure we should all be as happy as kings"* (Robert Louis Stevenson 1885)

Following on from the conceptual modeling exercises, central to the research methodology, is the activity of classifying aquatic organisms relative to their functional attributes as ecological engineers of wastewater treatment. To do this requires two levels of scientific investigation.

- 1. Investigating classificatory devices/systems at a biological level as detailed in this chapter.**
- 2. Investigating classificatory devices/systems at an ecological level. This is detailed in Chapter 7**

These two levels are interrelated i.e. functionality at the organism-centered level (biological) and group (ecological) level are to a certain extent inseparable. The decision to allocate a chapter to each relates not only to the fact that organisms are presently defined differently in biological and ecological terms (see Table 2.4) but also for practical reasons to prevent a chapter metamorphosing into a volume.

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 relates to 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. The amalgamation of the activities performed in this chapter and Chapter 7 enable the development of an 'ecotaxonomy' detailed in Chapter 8.

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) but the classifying of functional individuals (organisms) in ecological engineering terms is found not simply to be a question of species, genus or family etc. identification using such traditional biological classification.

6.2 A Critique of a Major Biological Taxonomic Systems

6.2.1 Taxonomy the Science of Classification

Taxonomy as

“..the theoretical study of classification including its bases, principles and rules” (Simpson 1961)

exists in many forms e.g. numerical and systematic, classical, biochemical and cytotaxonomical. This chapter concentrates on the classification of biological forms or individual organisms. Platonic scientific heritage has led to the human preoccupation with identifying separate entities or isolated ‘essences’. The nature of ‘essence’ however is an elusive one and dependent as ever on the context not only of that being defined but also the definer.

“But all evolutionary biologists know that variation itself is nature’s only irreducible essence.” (Gould, 1989)

The classification of the natural world is dominated by the Linnaean taxonomic system (Carolus Linnaeus, 1740) and this is detailed in Section 6.3. Although Linnaeus is often credited with developing biological classification he represents only part of the whole story. He did not recognise or accept the complementary role that developing evolutionary theory could play with respect to his taxonomy and although it is unsurprising given that evolution manifests itself in morphological change, it is in some ways lucky that his system seems to often coincide neatly with a “natural” phylogenetic* one.

6.3 Analyzing the Linnaean Taxonomic System

As mentioned in the last section the classification of the natural world is dominated by the Linnaean taxonomic system (Carolus Linnaeus {1707-1778} “Systema Naturae”- a C17th taxonomic Hierarchy or Binomial Nomenclature, 1736)

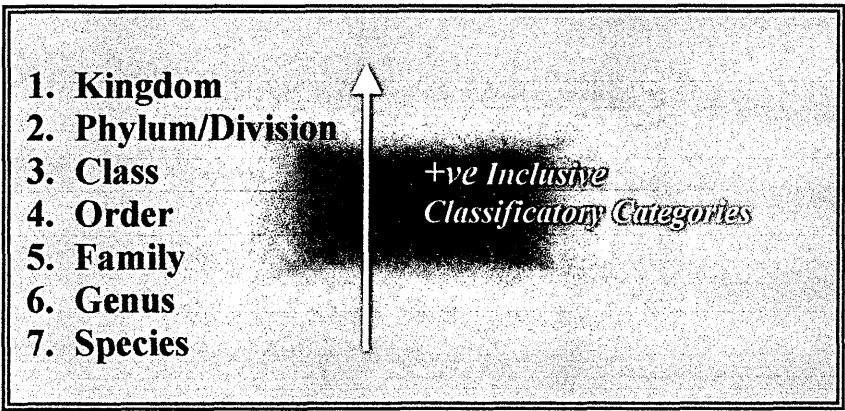
“This science of classification is often undervalued as a glorified form of filing with each species in it’s folder; but taxonomy is a fundamental and dynamic science, dedicating to exploring the cases of relationships and similarities between organisms. Classifications are theories about the basis of natural order, not dull catalogues compiled only to avoid chaos” (Gould 1989).

The Linnaean system describes each type of organisms by designating it two Latin name categories, genus and species. Genus is the higher level of these two categories and can encompass one or more species. This dual level designation is referred to as a binomen the Latin for “two names”. Linnaeus described humans using his taxonomic system using the binomen *Homo sapiens* (note the genus level is capitalized) which is Latin for “man who is wise”. The taxonomist himself was not immune to such classification as *Carolus Linnaeus* is actually the Latinized form of the Swedish botanist/medical doctor who was named at birth, Karl von Linné.

Familiar to all those *au fait* with the Biological Sciences the Linnaean system encompasses seven main taxonomic levels or ‘taxa’:

“Modern taxonomists recognise seven basic levels of increasing inclusion from species which is treated as the fundamental and irreducible unit of evolution to the broadest grouping of all, kingdoms” (Gould 1989)

Fig 6.1 Ranking the Taxa of the Linnaean Taxonomic System



This is the skeleton from which the family tree of any living organism can be constructed. It works by providing a framework by which organisms can be classified according to the extent of their similarities.

Table 6.1 The complete Classification of the Common Carp *Cyprinus carpio*

	<u>Taxa</u>	<u>Specific Taxon</u>
1	Kingdom	Animalia
2	Phylum	Chordate (subphylum – vertebratae)
3	Class	Pisces (sub grade Teleostei, sub class Actinopterygii)
4	Order	Cypriniformes
5	Family	Cyprinidae
6	Genus	<i>Cyprinus</i>
7	Species	<i>carpio</i>

All this serves to perform many viable functions, such as: species identification and cataloguing their relatedness whilst acting as a gauge with which to monitor levels of biodiversity* and to isolate groups of organisms of manageable size for study.

The merit of all the taxonomic levels or taxa however, in doing the above is questionable and the maintenance of consistency not always guaranteed, as is inadvertently illustrated by the following comment;

“All scientific (biological) classification is based on the brilliant idea of Linnaeus, over 200 years ago, to introduce a simple binomial system using a double Latin name for each and every species known to science. On top of this comes a kind of pecking-order in which species are grouped together in ever-vaguer combinations.”(BeeBee, 1992).

Vaguer is the operative word but there is often little consistency in the increments of vagueness as different groups are classified. There exists in biological literature a vast grey area as to where such categories overlap and deciding upon the increments of differences i.e. the boundaries between taxa and the terminology with which to describe them. The following example attempts to show this

Table 6.2 Similarities Between Taxa

Taxon Level of inclusion	Taxon	Examples of this Taxon
Kingdom	Animal	Vertebrates, Insects
Phylum (Sub)	Vertebrate	Mammals, Reptiles
Class	Mammal	Primates, Canines
Order	Primate	People, Apes

In this way vertebrates + insects = animals, mammals + reptiles = vertebrates, primates + canines dogs = mammals, People + apes = primates. Extrapolating from this results in statements such as primates + reptiles = vertebrates, which begs the question ; Does having a backbone make an ape more like a crocodile than say, a moth? The answer is affirmative in that such evolutionary landmarks as backbone development create an ensemble of other characteristics which converge e.g. four limbs and terrestriality, However how unlike a moth is an ape when compared to a crocodile, i.e. the reverse scenario, is more difficult to qualify.

When biological taxonomy is related to the most fundamental systematic principles i.e. via the attempted application of ‘Aristotelian’ logic to define the *essence* of a taxonomic group (See early systematists Aristotle, 427/8–347 B.C.,Cesalpino 1519-1603A.D and Linnaeus1707–1778 A.D. it does not tally as

“ biological taxonomy is a system of unanalyzed entities whose properties cannot be inferred from the definitions - at least if the taxonomy is to be a natural one in any of the usual senses.” (Sneath , Sokal 1973).

Critiquing each taxonomic level should not detract from it’s worth as a whole but should allow insight into possible flaws within the classification system even when it is used simply for the above. Classification into recognized groups is necessary for the purpose of discussion and communication about those groups, but whether such groups actually exist as real entities in nature or whether they are just the convenient

invention of taxonomists is a major question and probably depends upon the taxonomic level that is being considered.

The study of natural populations does show that living things do tend to occur in units that are distinctly different in form, ecology, genotype and evolutionary history and within which individuals resemble each other and between which there are generally no intermediate forms. Some taxonomic level must, then, be considered as real but there are still difficulties in defining this.

The most definitive level is that of the lowest taxa (least inclusive rank/highest numerically) i.e. species, because attempts to define it have actually been made and have been moderately successful. Even then the definition of species varies according to the occupation of the definer, a point that can be illustrated by overviewing the three commonly used definitions of species: the 'Evolutionary Species Concept', the 'Biological Species Concept' (Mayr, 1940) and the 'Recognition Species Concept' (Paterson, 1980).

The highest taxonomic level (rank), i.e. Kingdom, is also relatively clear because defining plants from animals, protozoa and fungi is generally quite simple (although there are problems when auto/heterotrophic symbiotic relationships are encountered). However the system as a whole tends to break down in the intermediary. For example species composing the Kingdom animalia are all related through some degree of common ancestry and any similarity in morphology is thus a reflection of their evolutionary relationship or phylogeny*.

Linnaeus, himself, began to doubt the unchanging nature of species when the crossbreeding of plants to create new varieties suggested the changing nature of life. He still however, stopped short at the idea of the evolution of species. Paradoxically, as evolution is often reflected in changing morphology his taxonomic system therefore tends to reflect evolutionary relationships.

Evolutionary theories aside, the Linnaean system serves the naturalists well and presently provides the most comprehensive framework for categorizing the natural world. But in order for such categorisation to be of use to the ecological engineer it requires an operational input/operationalization of biological taxonomic concepts and specifically in terms of this research the classification of organisms (all-be-it Linnean labels) in terms of changing water quality.

6.4 How Useful is Traditional Biological Taxonomy to the Ecological Engineer ?

For identification purposes the Linnaean system still offers the only real option. It does not, however, provide any information or clues regarding interrelationships of the organisms with one another or their environment. In order to be of use to ecological engineering, a classification is needed that does not simply classify an organism in isolation but identifies it's effects upon, and how it is affected, by surrounding physicochemical/biological elements. This ecological function is dealt with in Chapter 7.

Even when singular organism functionality is taken in isolation there are problems with the Linnaean system. The system designates that the species is the definitive level of taxonomy. This is because in evolutionary terms it is the definitive unit of organization but in an ecological engineering context species need not be treated as the last or even most useful division; further divisions could be useful. This is not a question of genetics i.e. the occurrence of hybrids or sub species etc. it is much more simple. Take, for instance, the question of life stages. Many species have separate and distinct lifestages and the differences exerted on the environment by these stages (or on the organism by their environment) may be greater than the sum of differences exerted between two different species and thus intraspecific relationships may be more profound as a consequence than interspecific ones.

Defining species may not be particularly useful as many different species of the same genus may exert identical effects within the ecosystem and therefore do not, from an ecological engineering point of view, need to be defined, although the stocking of systems may require species identification.

In order for a classification system to be useful to the water treatment plant manager, say, (who is not necessarily *au fait* with the Linnaean taxonomic system) it needs to be developed around the biological and ecological processes occurring in the system rather than simply relating to the evolutionary types (variety) of flora and fauna contained. In this way it would allow further complexity of classification to be incorporated i.e. not just the effects of individual organisms but also allow the cumulative effects that occur via their intra relationships to be studied. This idea is returned to in Chapter 7.

Thus certain elements from the traditional Linnean taxonomic system will remain functional and additional 'taxa' will need, in this context, to be added. Table 6.3 on the next page details the taxa, Linnaean and non-Linnaean, useful for developing an ecotechnological approach to ecological engineering.

Most text books recognise between twenty and thirty modern animal phyla. The most extensive compendium being that of Margulis and Schwartz (1982) which lists thirty two separate animal phyla whilst other authors further complicate issues by employing subcategories (subphyla/class etc). The general rule of thumb seems to be that...

"the anatomy of a group of organisms should not become sufficiently distinct to rank as a separate phyla until a great deal of diversity has accumulated after repeated speciation", (Gould, 1989).

But quantifying this diversity in any fashion (consistent or otherwise) is to all extents and purposes impossible. Even the number of the largest most inclusive taxon 'Kingdom' is the subject of heated debate within biological circles ...

"The highest taxonomic level is no longer split simply into plants and animals even the more recent division into plants, animalia and single celled protists has been superseded by a more convenient and accurate five-Kingdom system i.e.

contains Plantae, Animalia and Fungi for multicellular organisms; Protists (protoctista) for single celled organisms with complex (eukaryote) cells and Monera for single celled organisms (bacteria and cyanophytes) with simple (prokaryotic) cells devoid of nuclear membranes, mitochondria, and other organelles.” (Gould, 1989)

The ‘Five Kingdom System’ includes the prokaryotic (Kingdom Monera) ,eukaryotic unicellular (Kingdom protista) and eukaryotic multicellular (animalia and plantae) and eukaryotic multinucleate (fungi).

On each level there is a divergence in relation to the three principle modes of nutrition i.e. photosynthetic (autotrophic), absorptive and ingestive (heterotrophic). This is thus directly relevant to the environmental effect exerted by organisms in any ecosystem (from Whittaker, 1969). Many texts list only four kingdoms by combining the ‘lower protista’ (Monera) with the higher protista to form the ‘protista’. Evolutionary relations are very much simplified, particularly in the protista. Only the major animal phyla are entered, and the phyla of bacteria are omitted.

The following table illustrates, in addition to the essential Linnaean taxa, a functional group useful to ecological engineering, which is concealed by the traditional taxonomic system:

Table 6.3 Useful Functional Taxa?

<u>Taxa</u>	<u>Logic</u>
Non-Linnaean Life stage of species	For example larvae of two different species may act in the same way whilst operating in radically different ways to mid life/adult stages of the same species e.g. Chironomidae (non-biting midge family)
Linnaen Species	This taxon may be necessary for identification purposes when restocking/harvesting water systems, quantifying biodiversity in natural systems or to biomonitor pollution effects.
Linnaen Genus	This is generally a more useful label in that many species of the same genus, being morphologically similar are likely to exert identical effects upon the treatment system. Also the NRA (EA) already tend to use ‘Genus’ in their biomonitoring databases.
Linnaen Family, Order, Class	These taxa are not in ecological engineering terms strictly a necessity, the only real use that such intermediaries could possibly serve would be during the use of identification keys but these devices are often not consistent and depend on the literature used.
Linnaen Phylum	“This is the basic unit of differentiation within kingdoms. Phyla represent the fundamental ground plans for anatomy.” (Gould, 1989). Ensuring representatives of as many phyla as possible would maximise operational diversity within the ecosystem by imparting a variety of morphological structure. Natural water systems combining the widest trophic ensemble will therefore contain a greater representation of phyla relative to conventional biological treatment systems and the labelling
Linnaen Kingdom	Can represent even greater diversity of morphological character. Good basic definer of functionality for instance separates plants and animals i.e. autotrophs e.g. photosynthesisers and heterotrophs i.e. non-photosynthesisers.

The Linnaean classification system is therefore generally an appropriate one for identification of reproductive isolates (evolutionary types) but it cannot provide all the

relevant biological, let alone ecological, information necessary for ecological engineering purposes. It appears to lack necessary taxa i.e. life stages and ecological units. Having said this, the Linnaean taxonomy has stood the test of time well and is essential for the identification and restocking of aquatic systems.

The following section shows how the Linnaean system was used initially during the research simply to define candidate fresh water organisms which have some ecological engineering potential in terms of water quality change.

6.5 The Identification of Biological Taxa and Candidate Organisms Central to Water Quality Change

6.5.1 The Classification of Freshwater Organisms Using the Linnaean Taxonomy

The effectiveness of 'natural systems' for treating wastewater is well documented (e.g. Kadlec, 1996, Metcalf and Eddy, 1991, Mitsch and Jorgensen 1989).

In the UK it appears that 'natural systems' such as reed beds and treatment lagoons are frequently included by water companies as part of overall biological treatment, a fact which reflects their effective natural cleaning ability. However apart from physical factors such as sedimentation, little is done to monitor the biological mechanisms that impart this quality.

Aside from the obvious key organisms such as *Phragmites* reeds in a bed and algae species (*Anabaena*) in a lagoon etc, little monitoring of the organisms comprising the treatment biocoenosis is carried out. Any biological data collated is usually done so as part of biomonitoring surveys carried out by the Environment Agency (EA) formally the National Rivers Authority (NRA) and is used to test receiving water/effluent quality but not focused towards assessing treatment capacity.

"the macroinvertebrate species diversity index is the most widely used biological criterion for pollution control" (Kadlec, 1996)

Even the fauna of conventional small volume biological treatment processes such as Activated Sludge are not categorised extensively. The microbial communities (bacterial) have to exist in quantities to enable the works consent to be met but little attention is paid to the higher organisms which also comprise the treatment capacity such as the protozoa (single celled organisms) and invertebrates such as nematode worms.

Literature analysing the effectiveness of natural systems in treating wastewater does not generally provide a resumé of all the types of organisms which donate their treatment potential and tends to document the treatment potential of the system type as a whole e.g. macrophyte* systems for nitrate removal.

In order to investigate the living ensemble endogenous to such systems it is therefore necessary to collate information from disciplines such as limnology (the study of lakes), zoology, ecology and to use field guides for studying fresh water fauna.

Previous sections have revealed how biological taxonomists categorise organisms into hierarchical taxa of relatedness using the Linnean taxonomic system and it was therefore in this format that the common treatment fauna that comprise 'natural systems' biocoenosis can be listed on a database.

A database was created which classified freshwater organisms using the Linnaean taxonomy. Table 1 of the Appendices exemplifies this.

Using the Linnaean classification system to identify species is in many cases a task for specialised taxonomists, being outside the scope of the general biologist let alone the ecological engineer who could possess say a chemical/engineering background. The idea that such biological taxonomy is not essential to understanding ecological processes within the context of water treatment is not a new one.

"The inability to name species present in a treatment plant should not, however prevent one understanding the factors influencing their different activities in the process of water treatment" (Hawkes, 1963).

This was written with conventional biological treatment processes in mind e.g. activated sludge, bacterial beds etc, trickle filters but is even more relevant to the greater diversity of organisms that can comprise "natural" systems biocoenoses.

"The classification of organisms is based on structure and is no way ecological" (Hawkes, 1963).

This is rather an extreme statement and although to a certain extent it is congruent with this study, it is in its entirety simply not true. An organisms structure does designate limitations to the ecological niche it fills and can be seen as delineating an organism's individual complexity within that of the ecological system as a whole.

"Although it is desirable to be able to identify and classify organisms, it is the functioning and activity of the organism that determines it's role in waste water treatment" (Hawkes, 1963).

6.5.2 Lifestages

As was noted before functionality of an organism cannot be defined simply by giving it a specific name. Within species different life stages occur which react completely differently to their environment. A radical example is when one life stage is purely aquatic whilst another is amphibian, terrestrial or even aerial.

For example the following two species, the stone fly *Perla bipunctata* and the common frog *Rana temporaria* actually generate five eco-species i.e. types that will

respond and effect the aquatic system differently. This is shown in the following table. Appendix Table 5 gives more examples.

Table 6.4 Examples of Life Stages

<u>Common Name</u>	<u>Kingdom</u>	<u>Phyla/ Division</u>	<u>Class</u>	<u>Order</u>	<u>Family</u>	<u>Genus</u>	<u>Species</u>	<u>Life Stages</u>
StoneFly	Animalia	Arthropod	Insecta	Diptera	Plecoptera	<i>Perla</i>	<i>bipunctata</i>	Nymph
StoneFly	Animalia	Arthropod	Insecta	Diptera	Plecoptera	<i>Perla</i>	<i>bipunctata</i>	Adults
Common Frog	Animalia	Chordata Vertebrata	Amphibia	Salientia Anura	Ranidae	<i>Rana</i>	<i>temporaria</i>	Eggs
Common Frog	Animalia	Chordata Vertebrata	Amphibia	Salientia Anura	Ranidae	<i>Rana</i>	<i>temporaria</i>	Larvae/ tadpole
Common Frog	Animalia	Chordata Vertebrata	Amphibia	Salientia Anura	Ranidae	<i>Rana</i>	<i>temporaria</i>	Adults

6.5.3 Fresh water Aquaculture Organisms

It is also useful to note the diversity of aquatic organisms which can be usefully cultured. A selection of aquacultural organisms can be found in Table 4 of the Appendices.

It is interesting to note how little of the Linnaean taxonomic system is actually used to identify these organisms when the aquaculture (farming/husbandry) of them is of principle interest (See Chapter 4).

6.5.4 Saprobic (Saprobien) Bioindicators

The Linnaean system is also generally used to define pollution bioindicators. The EA usually identifies bioindicators to genus level. The Biological Working Party (BMWP) which was set up by the Department of Environment (DoE) and the National Water Council (NWC) to make a score card namely a ‘green gauge’ for the various invertebrates found in freshwater habitats, tends to only classify invertebrates to ‘Family’ level of the Linnaean system.

There is one very simple taxonomic system which defines organisms in terms of their tolerance to organic pollution and hence biochemical oxygen demand. This classification system is called the Saprobien (or Saprobic) system (Kolkwitz and Marsson, 1902, 1908, 1909) and it relates four major stages of organic pollution (fertilization) to specific kinds of organisms. This makes it a relevant classification system in the context of this research which is taking BOD as the principle biochemical parameter of interest. Reasons for this choice are given in Sections 1.3.3, 3.3 and 5.2.7).

The original saprobien system has actually been developed into biotic index by Pantle and Buck, (1955) which has been subsequently been modified by Liebmann, (1962). Although this research has used information and data collected using the biotic index the initial, experimental ecotaxonomy (Chapter 8) uses the four basic saprobic types

of the original Saprobien system. This was because such Saprobic information was required to define a single facet of an organisms ecological engineering potential and this meant, for reasons of practicality using, initially, at least, the simplest form of the Saprobic classification system. Thus preventing the creation of a new taxonomic structure that incorporated a relatively complex taxonomy which was actually designed from a biomonitoring and not an ecological engineering perspective. The risk of using the modified system would have been to create a new objective for an old classification system not designed to fulfil the research criteria. It seemed far more appropriate to simply use the relevant pieces of such a classification system and others (Chapter 7) to create a new taxonomy designed with ecological engineering in mind. Also it makes sense, in terms of time and effort, to, initially test out such a development using the simplest version. This allowed for the significance of its contribution to be ascertained before deciding whether to include a more involved version.

Table 6.5 - The Saprobien (Saprobic) Index

Process	Saprobic Stage	Water Quality Class
Primary process of decomposition	Polysaprobic	IV (no O ₂ , H ₂ S)
Secondary process of decomposition	A-Mesosaprobic	III (<50% O ₂ no H ₂ S) +ve DO*
Progressed 'mineralization' (See 3.2)	B-Mesosaprobic	II (>50% O ₂) -ve BOD
Completed mineralization	Oligosaprobic	I (O ₂ saturated)

DO*- dissolved oxygen

A brief resume of these four stages of fertilization and the examples of the organisms which can exist in each.

1. The **Polysaprobic group**, includes sewage fungus* organisms, bloodworms (confusingly this common name describes multiple types of organisms) and the aquatic larvae of certain non-biting (chironomid) midges which contain haemoglobin and are tolerant of organic pollution. Sludge worms or river worms, mud-dwelling oligochaete worms (e.g. tubifex) and the red bristle worms (polychaetes) of muddy shore. The air breathing rat-tailed maggot (*Eristalis tenax*) can live in grossly polluted water in which decomposition is primarily anaerobic. Such waters are characterised by an absence of most autotrophic* organisms but are dominated by bacteria particularly thiobacteria which are adapted to surviving hydrogen sulphide (H₂S). Fish are generally not present.
2. The **Alpha-mesosaprobic group**, also includes some traditonal sewage fungus* organisms such as the bacteria *Sphaerotilus natans*. The sewage fungus forms a mat across the system bed which is formed by strands of organisms. Some 'higher' organisms can reside in this zone including the water louse (*Asselus*) and can tolerate polluted water where decomposition is partly aerobic and anaerobic. The pollution in the polysaprobic zone is still severe.

3. The **Beta-mesosaprobic group**, The surface waters are characterized by rich submerged vegetation and abundant macrozoobenthos (Mollusca, Insecta, Hirudinae (leeches), Entomostraca*) and coarse fish such as members of the Cyprinidae family. Also this group includes organisms such as the Canadian pond weed (*Elodea canadensis*), some caddis fly larvae (trichoptera), eels (*Anguilla anguilla*) and the three-spined stickle back *Gasterosteus aculeatus*, which can tolerate mildly to moderately polluted water.
4. The **Oligo-saprobic group** including stone-fly nymphs (Plecoptera) and the river trout *Salmo trutta* are restricted to non-polluted water which may contain the mineralized products generated by the 'self-purification' of organic pollution. Sensitive species such as aquatic mosses, planaria* and insect larvae can be found. The dominant fish are game species such as salmonids

Table 6.6 below illustrates the Saprobien (Saprobic) biotic system although data using the updated Saprobien index of Pantle and Buck, 1955 has been used to ascertain the level of Saprobity of the Linnaean types generally, mostly to species or genus level, in addition to those Saprobic conditions the traditional bioindicators* types inhabit. The four organisms detailed in Table 6.6 are classified to genus level of the Linnaean taxonomic system and are not members of the same phylum unlike the organisms used by other biotic indices, such as the BMWP (see last section) which tend to only use invertebrate fauna. The reason such indices use invertebrate fauna is because they are generally used to classify the pollution of running waters and invertebrates remain relatively static in such systems and thus tend to represent a single locality.

From Table 6.6 it can be seen that the Saprobien index is not limited in which Linnaean taxa it can represent. The examples shown, for instance, straddle the Kingdom level with representation from both a Plantae and Animalia . This attribute makes it , although a simple index, ideal for including in the following classification activities of Chapter 8 and 9 where the entire biological variety in an aquatic system is analysed to investigate the ecological engineering potential with respect to organic loading.

Table 6.6 Examples of Saprobien Types Using Genus as the Linnaean Classificatory Taxa

<u>Common Name</u>	<u>Genus</u>	<u>Water Quality Saprobic Stage</u>	<u>Pollution Level</u>	<u>Quality Grade</u>
Water Flea	<i>Sida</i>	Oligosaprobic	Nil-Slight	1
Segmented Worm – (Oligochaete)	<i>Stylaria</i>	Beta-Mesosaprobic	Moderate	2
Fennel-leaved Pond Weed	<i>Potamogeton</i>	Alpha-Mesosaprobic	Heavy	3
Blood Worm	<i>Chironomus</i>	Polysaprobic	Extremely Polluted	4

6.6 Bacterial Classification as a Useful Functional Biological Taxonomic Model

There are functional classification systems for bacteria. Often these reflect the effect they have on their environment as opposed to their evolutionary history. The functional classification of bacteria may reflect the fact that prokaryote* based micro-ecologies are more usually subject to biotechnological control and investigation than eukaryote* based macro-ecologies, the latter including ‘higher’ organisms in addition to simpler forms.

From the simplified universal organic sewage decomposition relationship (Chapter 5 Section 5.2.7) it can be seen that simple cell material, bacteria, form the basis of a succession of ever more complex life forms which can be involved in the self purification of a water body.

Different types of bacteria obtain the energy and carbon from different sources. Phototrophic* strains acquire energy from light and chemotrophic* types from chemicals. The source of carbon which bacteria use to build their cell material offers further classificatory distinction. If the carbon comes from organic material the organism is termed a heterotroph*. If, however, it comes from carbon dioxide (as is the case in photosynthetic reactions) the organism is termed an autotroph. Note that these terms apply to higher organisms as well.

“Combinations of the four groups (phototroph, chemotroph, heterotroph and autotroph) exist, giving a rich variety of metabolic types.” (Grant et al 1996).

Table 6.7 The Classification of Bacteria- an example of a useful functional taxonomy
(adapted from Grant et al 1996).

<u>Category (taxa)</u>	<u>Energy Source</u>	<u>Carbon Source</u>	<u>Examples</u>
Photoautotroph	Light	CO ₂	Photosynthetic bacteria (all green plants).
Photoheterotroph	Light	Organic C	Some purple and green bacteria
Chemoautotroph	Chemicals	CO ₂	Nitrifying bacteria
Chemoheterotroph	Chemicals	Organic C	Most bacteria, fungi and animals

Such a functional classification of bacteria, although not, ‘natural’ or phylogenetic (related to the biological evolution of microbial variety) is, none the less, a useful one in any context where microbial (biotic) activity and environmental, (abiotic) change are of primary interest rather than the natural history of a microbial system.

6.7 Concluding Remarks on Biological Classification

“The logical fundamental unit is the individual organism. Hennig (1966) points out that the fundamental element of biological systematics is an individual at a particular point in time, a unit he termed a “character bearing semaphoront” (Sneath and Sokal 1973).

It is not, however the organism as an individual, which is, with respect to ecological engineering processes, the

“operational taxonomic unit {OTU}” (Sneath and Sokal 1973).

This is because ecological engineering requires investigating the way organisms interact with one another and their environment and this cannot be directly extrapolated from their functionality in evolutionary terms.

The following table illustrates the advantages and disadvantages of using the Linnaean taxonomy in an ecological engineering context.

Table 6.8 The Advantages and Disadvantages of using the Linnaean Taxonomy for Ecological Engineering

(Browne, Seaton & Jeffrey 2000)

<u>Advantages of using Linnaean Taxonomy</u>	<u>BUT</u>	<u>Disadvantages of using Linnaean Taxonomy</u>
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

It can be seen therefore that the Linnaean system as a hierarchy of ever more inclusive taxa spanning from species to kingdom is in the context of ecological engineering not a definitive classification system. It appears to lack necessary taxa i.e. life stages and ecological units.

If a classification system is designed to classify organisms in isolation from each other by locating them within a hierarchy of inclusion it cannot easily be extended to incorporate ranks of taxa which classify different combinations of the taxa it embodies. Such ecological taxa would deviate from the tendency for ever more inclusive categories to become smaller numerically i.e. it would oppose the nature of Linnean taxonomy as a whole. From this perspective the defining of ecologies would actually have to lie at the least inclusive terminus of the taxonomy with every possible combination of organisms (species and life stages) existing as a unique entity. This would render it totally impractical to attempt to classify communities as combinations of different organisms within the Linnean framework.

From extensive investigation of biological and water treatment data it became apparent that the useful functionality of the organism was no way apparent in its identification. In order to deduce the ecological engineering utility of particular organism types within a water quality change system it was necessary to investigate numerous literature sources to find out about:

- ◆ Life cycles and stages
- ◆ Pollution tolerance
- ◆ Feeding habits
- ◆ Ecological interactivity with other organisms and the environment
- ◆ Longevity
- ◆ Expense of stocking a system

In order to ascertain how different organisms could effect and be affected by relevant changes in the water quality and the other organisms around it the first four of the above bullet points were investigated to further to create the ecotaxonomy detailed in Chapter 8

Biologists are presently attempting to develop a new “natural” classification system which reflects organisms phylogeny by using new DNA sequencing techniques. Multi-disciplined teams are using new molecular classification (although it has been found that the sequential analysis of bases does not always reveal true evolutionary order) to develop the taxonomy. They are discovering that although morphologically similar many organisms traditionally ‘lumped’ together by the traditional biological taxonomy are in evolutionary terms far more distant relatives than previously thought. Such phylogenetic studies are related to perception regarding biodiversity and revealing evolutionary order. (Rainbow, 1999 *pers. com.*).

This research is not attempting to create a “natural” taxonomy as it is not preoccupied with biological relatedness *per se*. Instead it takes a novel approach to biological classification. It appears from the literature survey to be the first time a classification system has been developed with issue-based, interdisciplinary research in mind which is accessible to non biologist environmental practitioners as well as those *au fait* with the biological sciences. It is also original in its questioning of the utility of traditional classification systems whilst searching for such a new taxonomic development.

Chapter 7 investigates how organisms existing in water treatment systems can be classified as singular entities in the context of ecologically engineering a water quality change system centred around the reduction of suspended solids and biochemical oxygen demand. It requires the consideration of organisms not only as individual evolutionary isolates but also as interacting ecological components.

Chapter 7.

Exploring Useful Ecological Classification in the Context of Ecological Engineering Wastewater Treatment Systems

“Pollution absorption occurs by merit of natural biological cycles which establish a food chain of dependent communities capable of degrading organic material”
(Horan, 1990)

7.1 Introduction

In Chapter 6 the classification of organisms as isolated evolutionary types was explored. Although the biological sciences classify organisms in this way, such biological types do not exist as evolutionary islands but as constantly interacting biomasses.

In Chapter 2 (Table 2.4) it was noted that organisms can be classified differently at an ecological level, by the biological sciences discipline of ecology. Ecology has been described as the

“basic science of ecological engineering” (Mitsch & Jorgensen 1989).

Although this is debatable, ecological concepts such as trophic levels/relationships (Lindeman 1942), food webs and ecosystems etc. are central to the operationalization of ecological theory in both an ecological engineering and an ecotechnological context.

Although ecologists still identify individual organisms using the Linnaean binomial nomenclature they also define species according to their interactions rather than simply according to their natural history. Ecology can be defined as

“the study of relationships between living organisms and their environment....their energy flows” (Porteous 1996).

The idea of energy flow and food webs is central to the discipline of ecology (see Fretwell 1987 in Cousins, 1996).

Another concept central to the theory of ecology is that of ‘ecosystem’. An ecosystem can be simply defined as all the flora and fauna (plants, animals and microbes) which live in a defined zone (after Porteous 1996). In reality it is actually difficult to define the zone encapsulating the organisms or ecosystem in any meaningful way with respect to energy flow and food webs. McNaughton et. al. referred to ecosystems as

“structurally organized food webs” (In Cousins, 1996)

whereas the Tansley-Lindeman concept is that ecosystems are

“physical-chemical-biological systems” (In Cousins, 1996).

Cousins in his paper states that

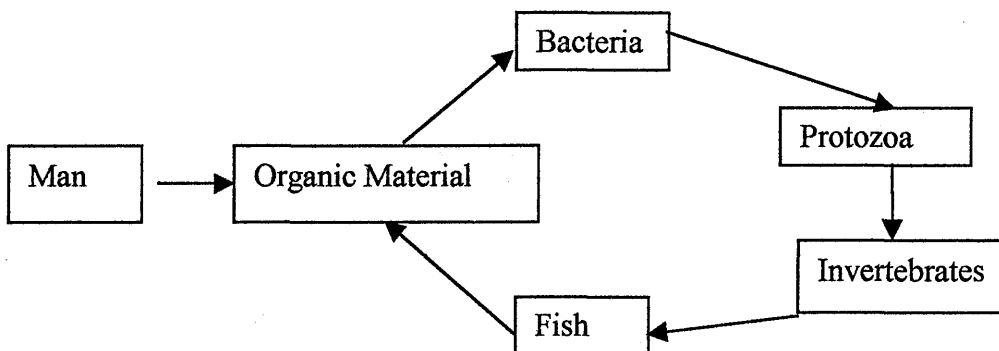
“a general theory of ecology should also exhibit a clear relationship to the theory of evolution and the domains of other sciences.....The requirement that any general theory of ecology should be consistent with the theory of evolution is met in the definition of the ecosystem as a reproductive lineage (Hull, 1974) and by the rejection of trophic level categories in favour of taxonomic categories from which to derive the properties of food webs (Cousins, 1985, 1988)” (Cousins 1996).

This, to a certain extent, mirrors the attempt by biologists to define a ‘natural’ cladistic* theory of biological classification in its need to reflect organisms evolution or phylogeny (6.7). When research is approached from a human issue context rather than from the ‘disciplinary’ need to define biological or ecological theories (ecosystems included) by the classification of organisms in terms of their natural history, then it is again necessary to define organisms as part of the context which is of interest, rather than simply from an evolutionary standpoint. The context in this thesis is water quality change and more specifically the ecological engineering (as ecotechnology) of organic changes in terms of solid and biochemical oxygen demand (BOD) dynamics in aquatic systems. As with the Linnaean system in Chapter 6 there will be some overlap, in that aspects of general ecological theory will prove helpful in terms of developing ecological engineering and ecotechnological theory. This is because ecology relates to the concept of interactions between group members and their environment and it is these which create the emergence of new functional organizational levels.

7.2 Trophic Levels

“Energy, chemical elements and some organic compounds are transferred from organism to organism through a sequence frequently described as a food chain. However such linear structures are rare and complex food webs are more typical” (Jones 1997).

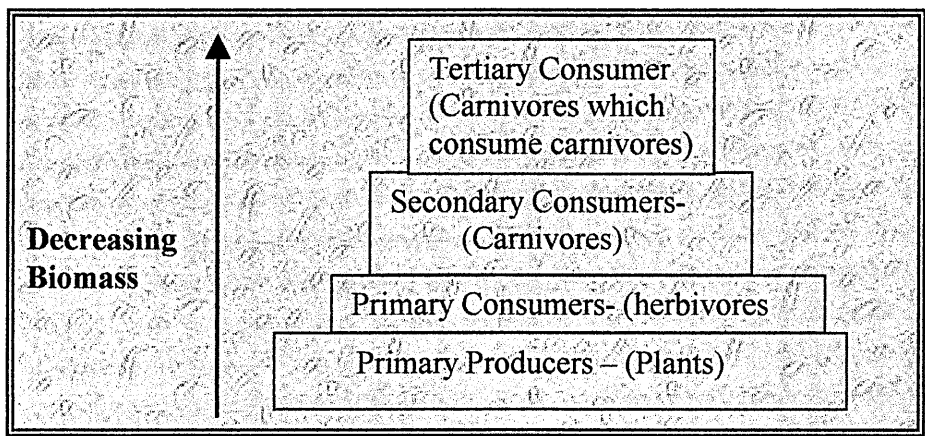
Fig 7.1 A Simplistic Representation of a Wastewater - Fed Aquatic Food Chain



“This ability of water to absorb and degrade organic pollution is known as its ‘self-purification capacity’ (see Section 3.1) .Only when this capacity is exceeded will a water body start exhibiting signs of pollution” (Horan 1990).

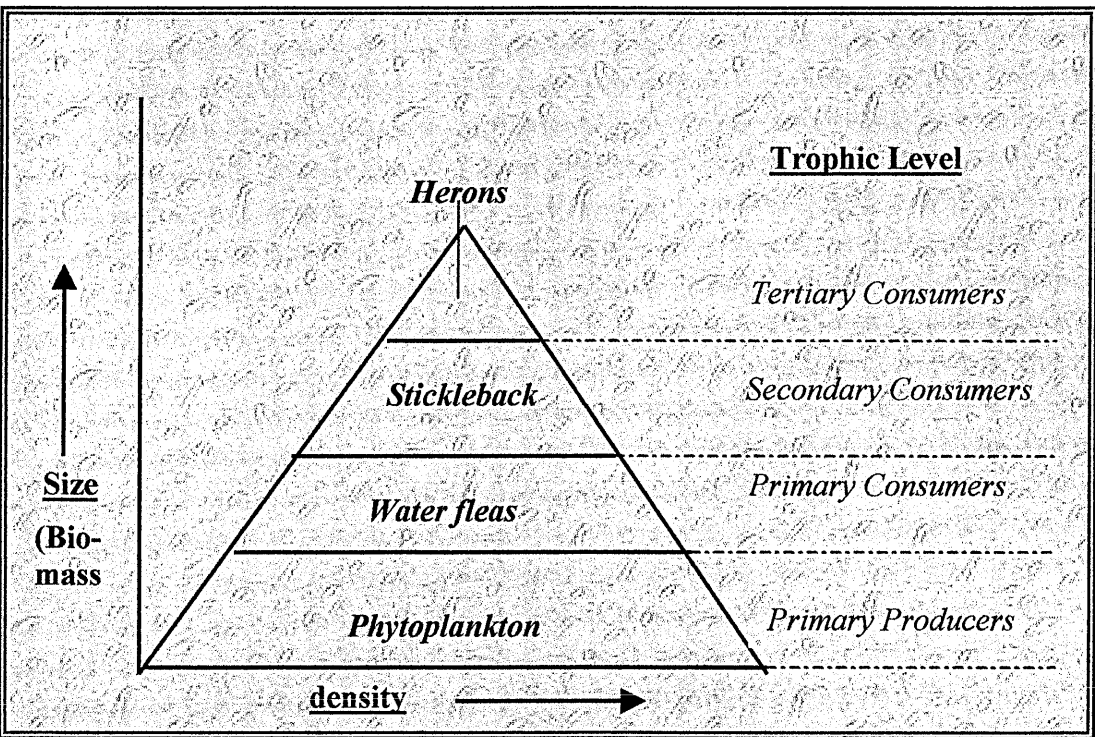
The organisms comprising such self-purifying food chains/webs can be categorized into trophic levels. Each trophic level contains all those types of organisms (defined by biological classification) which are at the same feeding level away from the original energy source, which is generally the sun, but which can also be other forms of chemical and thermal energy. Traditional trophic level classification which is based upon the principle functional relationship dictating ecological dynamics i.e. consumption and degradation in food chains/webs is therefore central not only to a systems ecology but also to the ecological engineering of it. In effect each trophic level can be perceived as separate ecological taxon.

Fig. 7.2 Traditional Trophic Classification of Organisms Generally



The following figure illustrates a possible pyramid of numbers in a pond ecosystem (note that the tertiary consumer is mostly situated outside the physical (aquatic) system)

Fig 7.3 Typical Pond Food Chain



7.3 Trophic Taxa

It can be seen that using the ecological concept of trophic levels at its simplest generates four simple taxa (ecotaxa) when a food chain/web terminates at the tertiary consumer level. In reality a fifth taxa, the decomposers has to be added representing the catabolic or breakdown of foodwebs comprising the other trophic types.

Table 7.1 Trophic Levels as Simple Ecological taxa

Ecological Taxon	Trophic Level
1	Primary Producer
2	Primary Consumer
3	Secondary Consumer
4	Tertiary Consumer
5	Decomposer

There are numerous problems associated with using the trophic level concept to define specific ecological types because, as is the case with the Linnaean system of biological classification, many organisms cannot be easily pigeonholed.

Problems when using trophic levels to define ecological type include the following:

- ◆ Many organisms feed at more than one trophic level
- ◆ Different life stages of the same species can occur at different trophic levels
- ◆ It is difficult to ascertain a trophic position for many decomposer varieties

Having said that, the categorisation of organisms into different trophic levels allows different lifestages of the same species, where the stages exhibit different eating patterns (such as when larval stages are carnivorous as opposed to herbivorous adult stages), to be classed differently in terms of their trophic position.

Ecology is usually defined as the interaction of organism with one another and their environment. Using trophic levels to classify ecologies might seem to exclude the organism/environment interrelationship by simply concentrating on a functional interaction between organisms. This is not, in fact, the case, within the context of water quality issues, because the relevant environmental aspect is the biochemistry encountered and at some level (directly or indirectly) this is consumed by the organisms.

“Waste water treatment may be regarded as resulting from the activity of organisms on one component of their environment- the waste being treated”
(Hawkes 1965, 1983).

7.4 Ecological Classification Activities

The need to define the interrelationships not only between water quality and organisms as individual functional and evolutionary units but also as organizations of them (ecologies/biocoenoses) involved the following research activities which related to the idea of collecting and analysing ‘relevant data’ (Section 5.2.3):

- 1. An investigation of ecological classification where trophic levels were used to dictate the position of organisms within a water quality change hierarchy.
- 2. Investigations of ecological models such as ‘Ecopath’ (Pauly and Christensen, 1993) and ‘Ecofate’([hp//www.cs.ssf.uca/rem/ecofate/ecofate.html](http://www.cs.ssf.uca/rem/ecofate/ecofate.html)) to check the variables used to see if they would be useful in an ecological engineering context.
- 3. The development of databases detailing the trophic levels of the organism detailed during researching of biological classification.
- 4. The development of databases and a binary matrix (Appendix Table 6) detailing the relativity of organisms to one another as consumers and prey (i.e.in trophic terms). Freshwater organisms were plotted against one another to produce a matrix and when there was a trophic function i.e. when organism *a* (x-axis) consumed organism *b* (y-axis) this was recorded as a positive interaction. This fourth research activity was somewhat restricted by the lack of specific data regarding what particular organisms eat.

The following tables presents, as an example, the binary matrix of a salmonid food web.

Table 7.2 Species/Types of Organisms Comprising the Salmonid (trout) Food Web

Species No.	Organism specific/type name	No. of prey types
1	Diatoms	0
2	Filamentous algae	0
3	Detritus (allochthonous)	0
4	Chironomid larvae	3
5	Simulium larva	3
6	Baetis mayfly nymph	2
7	Rithrogena mayfly nymph	2
8	Gammarus freshwater shrimp	2
9	Ancylastrum freshwater limpet	2
10	Herpobdella leech	3
11	Perla stonefly nymph	5
12	Polycentropus caddis larvae	6
13	Rhyacophila caddis larvae	3
14	Salmonidae newly hatched fry	4
15	Salmonidae older fish	9

Table 7.3 Binary Matrix of trophic relations in the salmonid food web

Positive or negative consumption of Sp. (species/type) X by Y

Sp. No	Y														
X	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
4	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—
5	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—
6	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—
7	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—
8	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—
9	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—
10	—	—	—	+	+	+	—	—	—	—	—	—	—	—	—
11	—	+	—	+	+	+	+	—	—	—	—	—	—	—	—
12	—	—	+	+	+	+	+	—	—	—	—	—	+	—	—
13	—	—	—	+	+	+	—	—	—	—	—	—	—	—	—
14	—	—	—	+	+	+	+	—	—	—	—	—	—	—	—
15	+	—	—	+	—	+	—	+	+	+	+	+	+	—	—

*Note: There are no instances of cannibalism in this particular web.

From this food web alone, and bearing in mind that an aquatic system (ecosystem) may be made up of numerous interacting webs of similar or greater complexity, it can be seen that there exists an array of positive trophic relationships (44 in total). Despite this it is possible to define all the above organisms in terms of the five afore-mentioned ecological categories (see Table 7.1). The five trophic taxa are, however, in no way reflective of an all encompassing ecological functionality. Plants are, for instance, all categorised as primary producers which gives no insight as to their ecological engineering potential or even their general “edibility” (Bracewell, 2000).

The binary matrix was developed to ascertain what was known about the nutritional habits of aquatic organisms as these form a major ecological interaction and thus are directly relevant to the ecological engineering of water quality systems.

7.5 The Correlations between Biological (Linnaean) and Ecological (trophic) Taxonomic Classes (taxa)

There is some correlation between the function of taxa classified by simple biological taxonomy shown in the previous chapter and ecological classification using trophic levels.

It is immediately obvious that the highest Linnaean taxa i.e. Kingdom (Fig.6.1); plantae and animalia equate to the trophic differentiation between producers and consumers. This has been noted elsewhere.

“Snaydon (1973) was perhaps the first to explore, somewhat briefly, the idea that higher taxonomic classes are functional classes in ecology”(Cousins 1996).

Table 7.4 Correlations Between Biological Taxonomic Groupings and Ecological Behaviour

Ecological Taxa	Taxonomic Groupings	Ecological Behaviour
1	Plants	Producer
2,3,4,	Animals	Consumers 1 ^o . 2 ^o and 3 ^o
5	Fungi	Decomposer

This table represents a food chain/web scenario, which terminates at the tertiary consumer level. It is possible to get longer food chains with higher consumer levels. The detritivore group is classed as the numerically highest group as it comprises organisms which are responsible for the break down of all dead material produced directly and indirectly by the death and metabolism of the other trophic levels.

It has also been argued that much of the appeal of Lindeman’s (1942) trophic levels lies with the ease of observing the interactions between taxonomic kingdoms. This correlation breaks down as lower biological taxonomic ranks are encountered and ecological (trophic) functional delineation becomes obscured.

This high level correlation between the way organisms are classified as biological and ecological units can be exploited more easily when it is the ecological engineering of systems which is of interest rather than the development of general ecological theory. In such a practical ecotechnological context it is of principal importance what different types of organisms remove, replace and transform from the system. The organisms within ecologically engineered systems are responsible for the processes which help generate it and classifying them in these terms means that both aspects of their individuality and their integration need to be included. Table 7.5 illustrates this.

Table 7.5 Correlations Between Biological and Ecological Classification in Ecological Engineering Terms

Biological Classification	Ecological Classification
Plants (Linnaean Kingdom Plantae) are generally gross oxygenators of the water column	Equates to the ecological trophic taxa; primary producers
Animals classified as the Linnaean Kingdom Animalia generally act as gross deoxygenators of the water column	Equates to the ecological trophic taxa; consumers
Species which are responsible for the direct removal of suspended and settled solid from the water column	Equates to primary consumers and detritivores (and heterotrophic bacteria consuming secondary consumers)
Species responsible for the indirect removal of suspended and settled solids from the water column	Equates to secondary (generally), tertiary and higher consumer levels

Table 7.5 represents the taxa from the traditional biological and ecological classification systems detailed which need to be included as part of a functional/ecotechnological classification. They are representative of what species do in a particular context. This is clarified and extended in Chapter 8 detailing the development of the 'ecotaxonomy'.

7.6 Concluding Remarks

In his paper Cousins states that

“Food webs are representations of ecological systems which are determined by two issues; the definition of the categories of the web and the nature of the interactions between them. These are mutually dependent, so that the selections of stocks (categories) determines flows (interactions) or vice versa. If a coherent theory of food webs is to develop it will come from the analysis of which categories to draw or which interactions to measure” (Cousins 1996).

In this chapter it is the ecological categorisation of organisms in terms of their simple trophic interactions which has been examined. From the perspective of developing ecological theory it is obvious that the trophic classification system is often crude and simplistic and not always a reflection of an ecological systems dynamics. It is, for instance, difficult to encapsulate the function of time within a fixed categorisation system of organism types.

In terms of ecological engineering and the development of ecotechnological theory, where the need is to map between knowledge domains both within the biological sciences and across the social/engineering and technological divide, such a crude classificatory tool can still provide useful insights into the biological workings of socially directed biophysical systems.

It appears that the integration of biological and ecological classification systems enables organisms to be, at a certain level, classified according to their functional role within an ecological water treatment hierarchy.

The functional role in this thesis pertains to changing the redox potential (via changing the biochemical oxygen demand (BOD) and dissolved oxygen (DO) levels) and the SS suspended (settleable) solid dynamics of an aquatic system. Unfortunately classifying organisms in a way useful to modelling their role in the phosphate and nitrate dynamics of a system is more difficult as both compounds are integral to all cellular material irrespective of organism type. This would mean that distinctions between taxa would have to be of a quantitative, rather than qualitative, nature and this would require even greater amounts of detailed biological data

The way in which the biological and ecological classificatory devices explored in this, and the last chapter, can be exploited in ecotechnologically, interdisciplinary ecological engineering terms is the subject of the next chapter.

Chapter 8.

The Development of an Ecotaxonomy for Classifying Organisms as Ecological Engineers of Specific Wastewater Treatment.

8.1 Introduction

Chapter 5 (section 5.2.3) identified the research gap as the requirement of a ‘new interdisciplinary methodology’ with which to collect and/or analysis ‘relevant’ data. Such a requirement was found to be taxonomic and related to a need to map data described by different disciplines, biochemistry, biology and ecology (section 5.2.7) This chapter documents the development of an ‘inter’ taxonomic system which allows context driven mapping between biological and ecological disciplines. Context driven mapping describes the activity of mapping between the variables which are relevant to the research issue. This process is central to interdisciplinary, ecotechnological research and is described in Chapter 1 (Section 1.2). The ‘inter’ taxonomic system developed is referred to as an ‘eco’taxonomy to reflect its ecotechnological potential for investigating the ecological engineering of social biophysical, ‘natural’ systems and more specifically in this thesis the organic loading of freshwater systems. To a certain extent it is a hybrid taxonomy as it combines aspects from both the biological (Linnaean) classification detailed in Chapter 6 and ecological (trophic) classification described in Chapter 7. The classification of organisms using this ecotaxonomy acts as a simple representation of a systems ‘functional diversity’ (Section 9.3) in ecotechnological terms as opposed simply to it’s ‘biological variety’ (Section 9.3) in evolutionary terms. It also enables both anthropocentric and anthropomorphic characteristics to be incorporated when describing “natural” systems.

In Chapter 4 the concept of using wastewater-fed aquaculture and in particular polyculture systems as a central ecological engineering model was investigated and in Chapter 9 secondary data taken from a wastewater-fed aquaculture and a lake case study are used to test the ecotaxonomic framework developed in this chapter.

8.2 Revisiting the Conceptual Model of Water Quality Change

Chapter 5 presented a conceptual model of water quality change. This model used, as a simple conceptual device, four organizational (mapping) levels. These are briefly described in the following table 8.1 on the next page.

At an emergent level the conceptual model detailed in Chapter 5 provides a simple holistic, interdisciplinary appreciation of this system of water quality change.

Table 8.1 The Four Organizational Levels Used in the Conceptual Model

<u>Organizational/Mapping Level</u>	<u>Submodel Engine/Driver</u>
1. Physico-chemical level	The simplified universal description (equation) of wastewater treatment in terms of organic loading $\text{Organic Matter} + \text{O}_2 + \text{NH}_4^{2+} + \text{P} \Rightarrow \text{New Cells} + \text{CO}_2 + \text{H}_2\text{O}$
2. Biological Level	Organism function (singular) according to gross function relative to changing water quality, solid and biochemical oxygen demand (BOD) specifically.
3. Ecological Level	Ecological (trophic) function in terms of organism interactions with one another and with the wastewater, specifically the solid and BOD component.
4. Social Level	The fertilization of aquatic systems via human activity provides the solid and BOD to drive the system i.e. produces the physico-chemical level.

The ideas illustrated in the conceptual model were then developed to create a method of re-classifying organisms according to their ecological engineering functionality in the context of water quality change.

8.3 Classifying Organisms as Context Driven Ecological Engineers

Studying the ecotechnological functionality of ecologies (as groups of organismal effects including those of humans), freshwater and otherwise, 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.” (Browne, Seaton, Jeffrey 2000).

Investigating the structure of functional (in this context) ecologies still requires defining, as singular variants, the organisms which comprise them. It was seen in Chapter 6 that organisms are usually classified using the traditional ‘Linnaean taxonomic hierarchy’ (Linnaeus, 1740) and although this classification is generally an appropriate one for the identification of reproductive isolates (evolutionary types), it cannot provide all the relevant biological information necessary for ecological engineering purposes (See Table 6.8)

As was seen in Chapter 5 the “self-purification capacity” of a natural system 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.

It was argued in the last chapter that 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, at all levels, 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 carnivorous types such as pitcher plants are also secondary consumers). This indicates that the isolated use of such biological and ecological classification is inappropriate for defining (identifying them by merit of their function) the biota of ecologically engineered systems.

8.4 Finding a Classificatory Solution : Mapping Biological Taxonomies

Classifying an organism's functionality in terms of the effect it has on its biochemical environment and vice versa 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 functionality in terms of solid dynamics and oxygen demand in fresh water systems. (This relates to the fact that the development of biological functions such as gaseous exchange and nutrient transfer are, to a degree, related to evolutionary history.) These new 'eco' 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, in this context, three simple stages. Each of these stages produces a taxonomic structure which goes some way towards defining organisms ecotechnologically with respect to a specified water quality changing potential.

8.5 A New Taxonomic Model

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 simply to their Linnaean kingdom status (Fig.5.8), 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 organisms which attach to the surface and use for example breathing tubes 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 tend to be either detritivorous organisms or primary consumers who feed upon the algal or detritivorous component of the system, less commonly i.e. after water exits traditional secondary treatment processes secondary consumers remove heterotrophic bacteria which also comprise the SS component (Table 3.2). Indirect solid removers will tend to 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, this first level of the ecotaxonomy is a simple hybridisation of traditional biological and ecological classifications and represents at this level a natural physical hierarchy based on food chains represented, all-be-it simplistically, by the trophic level classification system (Chapter 7). Only five ecotypes or ecospecies are derived from such a simple set of distinctions, as only the gross deoxygenating varieties of organisms are subdivided. It should be noted here that although, generally, the gross oxygenating component simply coincides with the plant component this is not a definitive state for several simple reasons, for example:-

- ◆ Plants respire at night and sometimes create an oxygen deficiency in the system, for example the eutrophication of waterways occurs when an excess of nutrients enable algae in an aquatic system to ‘bloom’. Such cases are examples of plants **directly** creating a gross deoxygenating potential.
- ◆ Floating macrophyte species such as the duck wead *Lemna* can, by their shading of the water surface, prevent algal growth and thus **indirectly** generate an oxygen deficiency in the water column although by their photosynthetic activity at the surface they will remain aerial oxygenators.

Table 8.2 The Five Simplest Ecotypes

<u>Ecotype Number</u>	<u>Contextual Ecological Engineering Function (Ecotaxon Description)</u>
1	Gross oxygenators
2	Gross deoxygenating direct solid removers
3	Gross deoxygenating indirect solid removers
4	Air gulping direct solid removers
5	Air gulping indirect solid removers

This is obviously not enough to successfully define an organism’s specific ecological engineering niche with respect to biochemical oxygen demand (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, surface (floating) macrophyte and emergent (as in emerging from the water surface and not ‘emergent properties’) macrophyte components. This taxonomic development then produces a total of fifteen ecotaxa/types. Table 8.3 on the following page details these.

This still does not produce specific enough ecotypes as it provides no useful criteria for isolating types which are likely to occur together in the same aquatic system and thus interact.

The Linnaean taxonomic system is specific with respect to reproductive isolation as reproduction is regarded as the principal biological function. In this case the requirement is different. There is a need to acknowledge which organisms can interact with one another ecologically in terms of changing water quality and although population dynamics, and thus reproduction, are part of this they are not necessarily foremost.

The most obvious barrier to organism interaction, whether direct or indirect, in an aquatic system is whether an organism will actually occur in the same system or rather in water of the same/similar quality. Therefore a simple system which classifies the water quality in which the interacting ecological engineering organisms occur can be used to provide further classificatory complexity.

Table 8.3 Adding the Spatial Component to Produce Fifteen Ecotypes

Ecotype No.	Contextual Ecological Engineering Function (Ecotaxon Description)
1	Surface gross oxygenator/ algae
2	Surface gross oxygenator/ floating macrophyte
3	Gross oxygenator /emergent macrophyte
4	Benthic-feeding,direct-solid-removing,gross-deoxygenator
5	Midwater- feeding, direct- solid –removing, gross-deoxygenator
6	Surface- feeding, direct–solid- removing,gross- deoxygenator
7	Benthic- feeding, indirect-solid- removing, gross-deoxygenator
8	Midwater-feeding, indirect-solid- removing, gross-deoxygenator
9	Surface-Feeding, indirect-solid –removing, gross-deoxygenator
10	Benthic-feeding,direct-solid-removing, air-gulper
11	Midwater-feeding, direct-solid-removing, air-gulper
12	Surface-feeding, direct-solid-removing, air-gulper
13	Benthic-feeding, indirect-solid-removing, air-gulper
14	Midwater-feeding, indirect-solid-removing, air-gulper
15	Surface-feeding, indirect-solid-removing, air-gulper.

If the Linnaean taxonomic system classifies the most exclusive taxon (i.e. species by merit of reproductive isolation) then the following ecotaxonomic development uses biochemical exclusion, and specifically, exclusion created by changing levels of biochemical oxygen demand (BOD).

Like the previous criteria which uses water column position such biochemical exclusion reflects the temporality and spatiality of organisms rather than directly reflecting morphological characteristics of body plan etc, although the two are obviously interconnected (adaptive function etc.). This classificatory level should possibly have been defined prior to the last two as it this criteria which defines functionality at the highest level by illustrating the type of system in which an organism can occur whilst the other levels dictate, to a degree, organisms interactive potential.

Here it is biochemical tolerance rather than organism water quality changing potential relative to position in the water column which defines using an element of spatiality, the taxon boundary. This classificatory level is, therefore, taking into account the relationship from abiotic to biotic whilst the other two were concerned with the biotic to abiotic relationship. Considering one of the main purposes of such an ecotaxonomy is to look at the effect that organisms (biota) have on their biochemical environment (abiota) it could be argued that including a taxon, which classifies the reverse, breaks the principle purpose of such classification. In actuality one of the principles central to this research is that the relationship between abiota and biota is bi-directional and as such it is imperative to include at some level in the ecotaxonomy the feedback from the non-living (environment) to the living organisms. It does this by incorporating the very simple biotic index, namely the ‘saprobic’ or ‘saprobien system’(Kolkwitz and Marsson, 1902, 1908, 1909) detailed first in Chapter 6. This biotic index as shown in the following table 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 (Tables 6.5 and 6.6).

Table 8.4 The Saprobic Index

Saprobic Stage	Process	Water Quality Class	
Polysaprobic	Primaryprocess of decomposition	IV (no O ₂ , H ₂ S)	+ve DO* -ve BOD
a-Mesosaprobic	Secondary process of decomposition	III (<50% O ₂ no H ₂ S)	
b-Mesosaprobic	Progressed mineralization	II (>50% O ₂)	
Oligosaprobic	Completed mineralization	I (O ₂ saturated)	

DO*- dissolved oxygen

The addition of these four saprobic types to delineate further taxa generates a sharp increase in complexity, resulting in sixty ecotaxa.

Table 8.5 The Final Sixty Ecotaxa

Ecotype No.	Contextual Ecological Engineering Function (Ecotaxon Description)
1	Oligosaprobic, surface, gross oxygenator/algae
2	B- Mesosaprobic, surface, gross oxygenator/algae
3	A- Mesosaprobic,surface, gross oxygenator/algae
4	Polysaprobic, surface gross oxygenator/algae
5	Oligosaprobic, surface, gross oxygenator/ floating macrophytes
6	B- Mesosaprobic, surface, gross oxygenator/ floating macrophytes
7	A- Mesosaprobic, surface, gross oxygenator/ floating macrophytes
8	Polysaprobic, surface, gross oxygenator/ floating macrophytes
9	Oligosaprobic, gross oxygenator/submerged macrophyte
10	B- Mesosaprobic, gross oxygenator/submerged macrophyte
11	A- Mesosaprobic, gross oxygenator/submerged macrophyte
12	Polysaprobic, gross oxygenator/submerged macrophyte
13	Oligosaprobic, benthic-feeding,direct-solid-removing,gross-deoxygenator
14	B-Mesosaprobic,benthic-feeding,direct-solid-removing,gross-deoxygenator
15	A-Mesosaprobic,benthic-feeding,direct-solid-removing,gross-deoxygenator
16	Polysaprobic,benthic- feeding, direct-solid-removing, gross-deoxygenator
17	Oligosaprobic, midwater-feeding,direct-solid-removing, gross-deoxygenator

18	B- Mesosaprobic, midwater-feeding, direct-solid-removing, gross-deoxygenator
19	A-Mesosaprobic, midwater-feeding, direct-solid-removing, gross-deoxygenator
20	Polysaprobic, midwater-feeding, direct- solid –removing, gross -deoxygenator
21	Oligosaprobic, surface-feeding, direct- solid- removing, gross- deoxygenator
22	B- Mesosaprobic, surface-feeding, direct-solid-removing, gross-deoxygenator
23	A- Mesosaprobic, surface-feeding, direct –solid-removing, gross- deoxygenator
24	Polysaprobic, surface- feeding, direct –solid-removing, gross- deoxygenator
25	Oligosaprobic, benthic-feeding, indirect -solid-removing, gross- deoxygenator
26	B-Mesosaprobic, benthic-feeding, indirect-solid-removing, gross-deoxygenator
27	A-Mesosaprobic, benthic-feeding, indirect-solid-removing, gross-deoxygenator
28	Polysaprobic, benthic-feeding, indirect-solid-removing, gross-deoxygenator
29	Oligosaprobic, midwater-feeding, indirect-solid-removing, gross-deoxygenator
30	B-Mesosaprobic, midwater-feeding, indirect-solid-removing, gross deoxygenator
31	A-Mesosaprobic, midwater-feeding, indirect-solid-removing, gross-deoxygenator
32	Polysaprobic, midwater-feeding, indirect-solid-removing, gross-deoxygenator
33	Oligosaprobic, surface-feeding, indirect-solid-removing, gross deoxygenator
34	B- Mesosaprobic, surface-feeding, indirect-solid-removing, gross deoxygenator
35	A- Mesosaprobic, surface-feeding, indirect-solid-removing, gross deoxygenator
36	Polysaprobic, surface-feeding, indirect-solid-removing, gross deoxygenator
37	Oligosaprobic, benthic-feeding, direct-solid-removing, air-gulpers
38	B- Mesosaprobic, benthic-feeding, direct-solid-removing, air-gulpers
39	A- Mesosaprobic, benthic-feeding, direct-solid-removing, air-gulpers
40	Polysaprobic, benthic-feeding, direct-solid-removing, air-gulpers
41	Oligosaprobic, midwater-feeding, direct-solid-removing, air-gulpers
42	B- Mesosaprobic, midwater-feeding, direct-solid-removing, air-gulpers
43	A- Mesosaprobic, midwater-feeding, direct-solid-removing, air-gulpers
44	Polysaprobic, midwater-feeding, direct-solid-removing, air-gulpers
45	Oligosaprobic, surface-feeding, direct-solid-removing, air-gulpers
46	B- Mesosaprobic, surface-feeding, direct-solid-removing, air-gulpers
47	A- Mesosaprobic, surface-feeding, direct-solid-removing, air-gulpers
48	Polysaprobic, surface-feeding, direct-solid-removing, air-gulpers
49	Oligosaprobic, benthic-feeding, indirect-solid-removing, air-gulpers
50	B- Mesosaprobic, benthic-feeding, indirect-solid-removing, air-gulpers
51	A- Mesosaprobic, benthic-feeding, indirect-solid-removing, air-gulpers
52	Polysaprobic, benthic-feeding, indirect-solid-removing, air-gulpers
53	Oligosaprobic, midwater-feeding, indirect-solid-removing, air-gulpers
54	B- Mesosaprobic, midwater-feeding, indirect-solid-removing, air-gulpers
55	A- Mesosaprobic, midwater-feeding, indirect-solid-removing, air-gulpers
56	Polysaprobic, midwater-feeding, indirect-solid-removing, air-gulpers
57	Oligosaprobic, surface-feeding, indirect-solid-removing, air-gulpers
58	B- Mesosaprobic, surface-feeding, indirect-solid-removing, air-gulpers
59	A- Mesosaprobic, surface-feeding, indirect-solid-removing, air-gulpers
60	Polysaprobic, surface-feeding, indirect-solid-removing air-gulpers

The aim of this exercise is to define organisms in terms of a specified 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 (including the relevant abiotic components) 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 reduction

of solids and biochemical oxygen demand (BOD) from the water mass, are taken and mapped to generate a simple functional taxa.

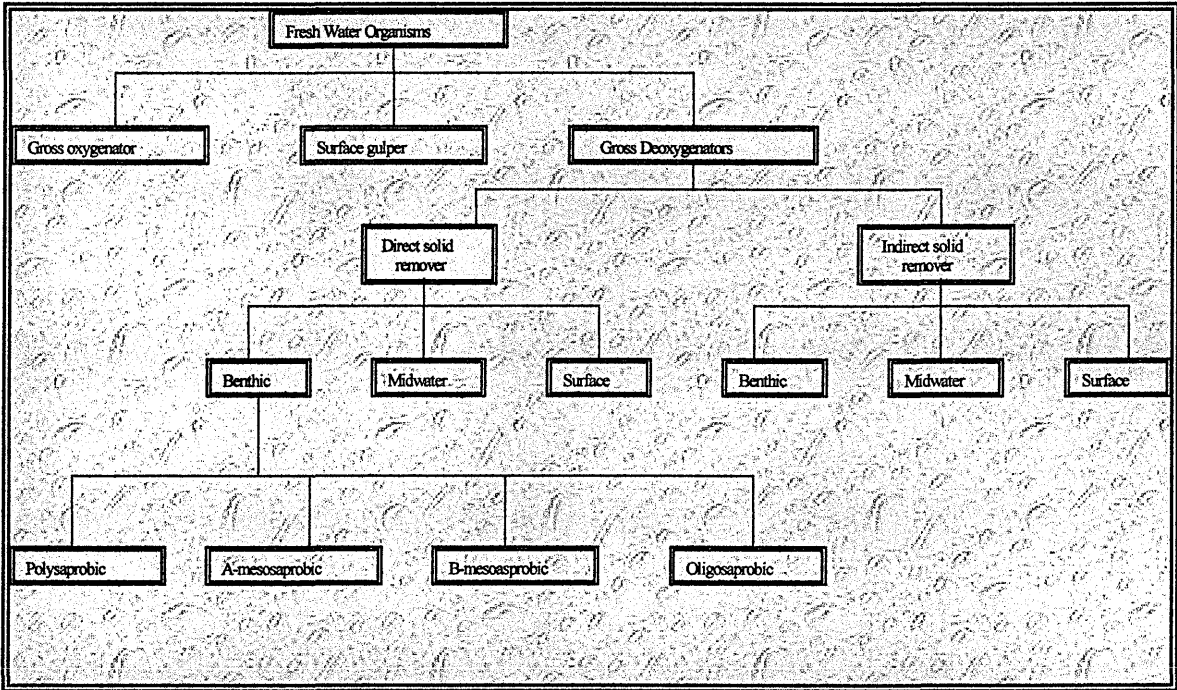
The structure of the new taxonomy is asymmetrical and not hierarchical, unlike the Linnaean taxonomic system. The significance of this is noted in Section 10.4.2. It is not an attempt to create a ‘natural’ taxonomic hierarchy. For example the tubificid *Tubifex tubifex* worm regularly found in heavily organically loaded water can be classified using the Linnaean taxonomic hierarchy in the following way;

Table 8.6 The Linnaean Classification of Tubifex tubifex

Taxon Rank	Taxon
Kingdom	Animalia
Phylum	Invertebratae
Class	Polychaeta
Order	Oligochaeta
Family	Tubificidae
Genus	Tubifex
Species	Tubifex tubifex

Whereas the ecotaxonomic classification would simply classify the freshwater organism in a non-hierarchical fashion as a polysaprobic, benthic, direct-solid-removing, gross deoxygenator and thus simply only uses a four-fold ranking system as opposed to the Linnaean System which uses, at it’s simplest, seven hierarchically ordered ranks. The application of ecotaxonomy to classify *Tubifex tubifex* is illustrated in the following figure.

Fig 8.1 The Ecoclassification of a Polysaprobic, Benthic, Direct- Solid -Removing, Gross- Deoxygenator such as Tubifex tubifex



The following table 8.7 gives further examples of the reclassification using the developed ecotaxonomy:

Table 8.7 Further Examples of Reclassification Using the Developed Ecotaxonomy

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

(Browne, Seaton and Jeffrey, 2000)

The following chapter outlines the way in which organisms classified in the case studies were re-classified using the ecotaxonomic framework and details how this reflects the ecotechnological, ecological engineering ‘ functional diversity’ (Section 9.3) of the aquatic systems as opposed to their ‘biological variety’ (Section 9.3).

Chapter 9.

Testing the Ecotaxonomic Framework – An Exercise in Re-Classification

9.1 Introduction

This chapter concludes the development of the methodology. By testing the taxonomic developments detailed in the last chapter it operationalizes the ideas developed in the conceptual model of Chapter 5. The analysis of data taken from the two case studies is used as a platform to test hypotheses concerning the taxonomic developments i.e. the ecotaxonomy.

The significance, of the following classificatory exercise is described, both in practical terms of assessing water quality parameters and intellectually in terms of mapping between sub-disciplines in order to express 'biological variety' as 'ecofunctional diversity' (Table 9.2) within systems.

The following is also an epistemological exercise investigating the way in which knowledge of particular systems can be transferred between disciplines/sub-disciplines and in the process be made more accessible to a greater audience via a process of simplification.

9.2 Operationalizing the Theory: The Reclassification of Biological Data

The utility of the ecotaxonomy to classify a systems specified ecological engineering functionality required the use of secondary data. This provided the biological data detailing the Linnaean taxa (species and genus generally) which required reclassification

Case-studies which exhibited comprehensive, extensive identification of the biological variety present in relevant aquatic systems (i.e. that documented as many species types as possible) were chosen. The rationale for the case study choice is further detailed in the Chapter 5 on the Research Design Process in Sections 5.2.9 and 5.2.10

In Chapter 3 it was seen that wastewater-fed aquaculture systems and more specifically wastewater-fed polyculture systems could provide a useful example for investigating the ecological engineering capacity of biologically diverse systems.

Two case-studies were chosen to provide the secondary data with which to analyse the ecotaxonomic framework.

The case studies chosen were entitled:

1. *"Artifacts or Attributes ? Effects of Resolution on the Little Rock Lake Food Web."* (Neo D Martinez 1991)

2. *“Wastewater-fed Fishculture in Hungary”* J. Olah 1990 (experimental studies 1974-1978)

These two particular experiments were extracted from other articles documenting biological variety in aquatic systems by merit of the following attributes:

- ◆ The detail of the ecological complexity involved i.e. they recorded extensively the species of organisms present in the system.
- ◆ The detail of the biochemical and physical parameters relevant to the taxonomic development (i.e. BOD biochemical oxygen demand and levels of Saprobity).

A further overview of the two case studies can be found on the next page in table 9.1

Although only these two separate case-studies were used to generate secondary data they actually provided three separate data sets. This was due to the fact that the Hungarian aquaculture case study (Olah,1990) referenced two separate sets of monitoring data recorded for 1971 and 1972 (Ponyi et.al 1973, 1974.).

The Hungarian case-study was chosen in particular because:

- ◆ It represented a wastewater-fed polyculture system (refer to Chapter 3)

The organisms detailed in the Limnological studies accompanying the case study are generally categorized to species or genus level using the Linnaean taxonomic system. A table in a Microsoft ‘Access’ database was created to record all the Linnaean / trophic species and the reclassification of them according to the ecotaxonomic framework. This was done using the stage criteria presented in Section 8.5. Appendix Tables 7,8 and 9 detail this. From this database graphs were produced to compare the patterns of Linnaean species and ecotaxonomic “ecotypes”. The former was taken to represent the biological, evolutionary variety of the system whilst the latter represented context relevant functional diversity in ecological engineering terms (Section 9.3).

Before documenting the data analysis some of the terms and data sets used during the development of the ecotaxonomy need to be described.

Table 9.1 An Overview of the Two Case Studies Chosen to Test the Internal Mechanics of the Ecotaxonomy

<u>Martinez Case Study</u>	<u>Olah Case Study</u>
<p>This case study of a “natural” freshwater system, forms, to a degree, the control basis with which to test diversity in a system undisturbed by “artificial” organic loading.</p> <p>It was chosen because:</p> <ul style="list-style-type: none"> ◆ It also, like the Hungarian case-study, reflects conditions in a Temperate Zone. ◆ It uses extensive limnological data with many organisms being identified to species level. <p><i>“The food web of Little Rock appears to be the first highly and evenly resolved food web of a large natural ecosystem originally documented for the purpose of examining quantitative foodweb patterns. This ecosystem food web contains roughly twice as many species as the largest web to date.”</i> (Martinez 1991).</p> <ul style="list-style-type: none"> ◆ In addition it also uses a binary matrix to show the consumption functions in the system (like Table 7.3 and the Appendix Table 6 created by this research.) ◆ It uses cluster analysis and taxonomic manipulation which equate, to a certain extent, with ecotaxonomic ideas e.g. the dividing of groups into “<i>trophic species</i>” (Briand and Cohen 1984). ◆ It details the limitations/completeness of the limnological data used. <p>Several problems particular to this case study include:</p> <ul style="list-style-type: none"> ◆ Many of the species are only identified to genus level. ◆ Macrophytes are not included as there was no taxonomist qualified to identify them ◆ Saprobic status of the organisms is not documented in the paper <p>The Little Rock study generates its own interesting hypotheses which are also inextricably linked to this research i.e. the difficulty in separating the meaningful functional attributes central to (ecological) complexity from those attributable to data ascertainment and classificatory bias.</p>	<p>It was decided that “<i>Wastewater-Fed Fishculture in Hungary</i>” J. Olah 1990 (studies in 1974-1978), “<i>Wastewater-Fed Fishculture in Hungary</i>” (J Olah 1988, 1990) and accompanying limnological investigations of Ponyi et. al., 1973 could be used to assess the utility of the ecotaxonomy. This was a particularly good case study as it reflected conditions in a wastewater-fed polyculture (fishculture) and thus related to wastewater-fed aquaculture as a principle example of ecological engineering (see Chapter 3).</p> <p>It was also chosen because of:</p> <ul style="list-style-type: none"> ◆ The substantial accompanying limnological detail which was chronicled in separate texts ◆ The temporality which was tested ◆ The interdisciplinary approach taken toward documenting the different genera of organisms i.e. biologists, algologists, limnologists and bacteriologists were all recruited to research the system. <p>Weaknesses of this study include:</p> <ul style="list-style-type: none"> ◆ The tendency for multiple parametric changes between tests e.g. loading rates and fish stocking quantities are changed simultaneously. <p>It was felt, however, that this study had the most to offer in terms of assessing the taxonomy of an ecologically complex system by relating its functional diversity to its species variety in order to identify its functional ecological complexity.</p>

9.3 Terms and Definitions

In the last chapter the terms “ *biological variety*” and “*functional diversity*” were mentioned. Prior to the data analysis these terms need to be defined within the research context i.e. freshwater water quality change systems. The two terms can also be defined within wider ecological and systems theory.

It can be seen that whilst the Linnaean taxonomic system (Chapter 6) provides the concept of ‘biological variety’ via the classification of morphological similarity (which often coincides with the evolutionary process), it is ecological classification which attempts to classify by rules of integrating aspects of this biological variety. One of the most obvious examples of this is found in the trophic relationships, which exist between organisms whereby the effect of one individual upon another in terms of consumption directly and physically alters the environment in which they exist.

‘Functional diversity’ in this research can equate to the use of the term diversity in the ecological sciences when it is not simply the richness or the variety of species found in the various ecological locales which is being denoted but the degree to which different species enjoy an equivalent functional representation. In this research this functional representation relates to changing water qualities and in particular biochemical oxygen demand and solid dynamics. This functionality is directly related to the way in which organisms derive the energy to sustain them and thus crudely to their trophic niches. It has been redefined in non-biological terms to relate to the water treatment, issue driven context of the research

Table 9.2, below, defines the terms ‘biological variety’ and ‘functional diversity’ in this context.

Table 9.2 Definitions of “Variety” and “Functional Diversity” in this Context

Biological Variety	Ecofunctional Diversity
This generally equates to the number of taxa defined as the lowest Linnaean hierarchical level present within the system, that is, the number of species. In other words variety within the aquaculture system is dictated by the number of the lowest defined Linnaean rank it contains. Although this is generally the number of species, when organisms are not identified to this level variety can be defined at the genus level. Many biomonitoring systems such as the BMWP (section 6.5.4) only identify biological variety to the family level.	This equates to the number of different functional niches which can be filled by the variety of species within the aquaculture system. The functionality of these niches and the ‘functionalism’ of their integration is dictated by the ecotaxonomy. This classificatory framework is, itself, dictated by the need to amalgamate the aspects of biological and ecological classification defined by the research context of changing water quality, more specifically by the dynamics of changing biochemical oxygen demand and solid levels within the system.

In this thesis ‘biological variety’ equates to the number of organisms in a system classified by merit of the Linnaean taxonomic system i.e. generally the number of species and/or genuses. The ‘functional diversity’ or ‘ecofunctionaal diversity’ relates to the number of taxa that result from the ‘biological variety’ being reclassified using the new ‘ecotaxonomic’ framework described in Chapter 8.

9.4 Data Sets – Detailing the Case-Studies

i) Case-Study 1. “Little Rock Lake Food Web”

This is an example of an unaffected (in terms of organic loading) fresh-water system and the reason for initially choosing this and not a sewage-fed aquaculture case study was to test the internal mechanics of the ecotaxonomy. A ‘natural’ freshwater system, after all, could form, to a degree, a control basis with which to test diversity in a system which is not disturbed by artificial organic loading.

This ecosystem foodweb contains roughly twice as many documented species as the largest web recorded prior to the article in 1991. This makes it the most comprehensive set of secondary data that could be acquired for this research. Only aquatic organisms, which spend virtually all the specified lifestage at or below the lake surface, were included in the web. This level of comprehension about the ‘biological variety’ of the system was aided by the analysis of fish gut content data. The definitions and procedure used in this case study produced a food web of some 182 taxa most of which were phytoplankton and benthic invertebrates. Field ecologists managed to designate prey and predators for 174 of these 182 taxa from ‘first hand familiarity’ and literature on feeding habits and natural history.

Most vertebrates and zooplankton are classified to species level but in addition Martinez actually reclassifies Linnaean species as “*trophic species*” in a way somewhat concurrent with the ecotaxonomic development and especially ideas encountered in Chapter 7. It is interesting to note that less “*trophic species*” than Linnaean species are recorded.

The ninety-three “*trophic species*” recorded included the classification of life stages and organic matter as separate “*trophic species*” Some vertebrate and zooplankton are divided functionally into different “*trophic taxa*”. Examples include;

- ◆ Yellow perch are separated into a taxon called ‘young-of-year’ and a taxon called ‘year-plus’ because the life-history stages have different sets of predator and prey.
- ◆ Fish eggs are considered a separate taxon, which includes all fish species eggs.
- ◆ Many species of juvenile zooplankton are grouped into a single “*trophic taxon*” e.g. several juvenile copepod* species are in a taxon called nauplii*.
- ◆ Many taxa of phytoplankton and benthic species are resolved only to genera and sometimes only to family. All organisms in a taxon are assumed to have identical predator and prey sets for this analysis.

The food web of Little Rock appears to be the first highly and evenly resolved food web of a large natural ecosystem originally documented for the purpose of examining quantitative foodweb patterns.

Unfortunately macrophyte* taxa were not included in the survey, although it appears that trophic relationships concerning macrophytes tend to involve the epiphytic* filamentous algae which were included in the web.

ii) Case-Study 2 “ The Hungarian Wastewater-Fed Fish Polyculture (Aquaculture) System”.

Data were collected during 1971 and 1972 from the same pond and canal system, which served for the post purification of the sewage-water from the Fonyod resort centre. The treated water was subsequently emptied into the nearby Lake Balaton. The key article, itself detailed experiments using aquaculture systems to purify water in addition to yielding carp. It gave a more detailed account of the reduction of waste substances than the limnological investigations but lacked in biological data i.e. it did not record the variety of species present in the system. These data on ‘biological variety’ were therefore obtained from the accompanying limnological investigations

An experimental farm was built near to the old sewage fishpond system used in the two limnological investigations. The performance data of the experimental systems in terms of the reduction of biochemical oxygen demand and solids or nitrates, phosphates and hydrogen sulphide dynamics cannot unfortunately actually be related directly to the limnological data to enable cross referencing with other such projects. However other articles detailing such wastewater- fed systems do not include such comprehensive limnological listings of the species types present in such aquatic systems. Usually such projects only express interest in the organisms being cultured (or ones which directly remove pollutants) and occasionally the other species which these key organisms are directly reliant upon. In this way the variety which comprises the subsidiary web is not, generally, detailed. The extensive limnological data from the Hungarian case-study can still be used, however, to test the development of the ecotaxonomy.

It is important to remember that with any ecological investigation the identification and categorisation of the variety of organisms present in a system is limited by the researching skills available. The fact that an interdisciplinary team of algalogists, bacteriologists and zoologists worked on these case studies suggests that the study was a highly comprehensive one.

9.5 Testing the Ecotaxonomic Model

9.5.1 Reclassifying the ‘Biological Variety’ Data Using the Ecotaxonomic Framework

Tables 7, 8 and 9 in the appendices detail the reclassification of data from the two case-studies. Each different type (in Linnaean terms) of organism is firstly identified by a common name or group term (vernacular) and then by its Linnaean specific i.e. species binomen (6.3) although many organisms in the “Little Rock” case-study were only identified to genus level.

The three columns headed 'Ecotaxonomic Development 1', 'Ecotaxonomic Development 2' and 'Ecotaxonomic Development 3' relate to the three development stages described in Section 8.5 of Chapter 8 and detailed in Tables 8.2, 8.3 and 8.5. Each species/genus identified is therefore re-identified numerically by merit of each of these developmental stages i.e. firstly by their simplest "ecofunctionality", secondly via this and their position in the water column and thirdly by adding their biochemical tolerance to biochemical oxygen demand (BOD) to the previous classification. The number designated to each organism in the last column therefore represents the organisms Ecotaxon (Ecotype) identifiable from Table 8.5.

The following two examples represented in Fig. 9.1 illustrate the process of reclassification firstly of a plant species and secondly an animal species.

1. The plant example re-classifies a blue-green algae (cyanobacteria*) species *Anabaena spiroides*. This is a member of a genus familiar to traditional water treatment systems, which often use algae in waste stabilisation ponds. There is a dichotomy with the ecological engineering potential of certain algae species. On the one hand they can be usefully harnessed in managed ponding systems whilst on the other the offloading of algae-laden effluents into 'natural' waterways can become problematic. The advantageous ecological engineering of algae is summed up in the following

"In aerobic or facultative ponds, photosynthesis is necessary to maintain a detectable dissolved oxygen content. The normal transfer of oxygen across the surface by diffusion or natural mixing is inadequate. In addition the algal systems consume carbon dioxide, thereby elevating the pH during daylight hours. Algae use ammonia, and so eliminate an oxygen demand normally inherent in the bacterial nitrification of ammonia to nitrite or nitrate. They are also involved in the reduction of other plant nutrients. Photosynthesis and respiration predominate alternatively, and this results in conservation of energy. Finally the aerobic bacteria rely upon dissolved oxygen, which is supplied in part by algae and surface aeration" (Gloyne, WHO 1971).

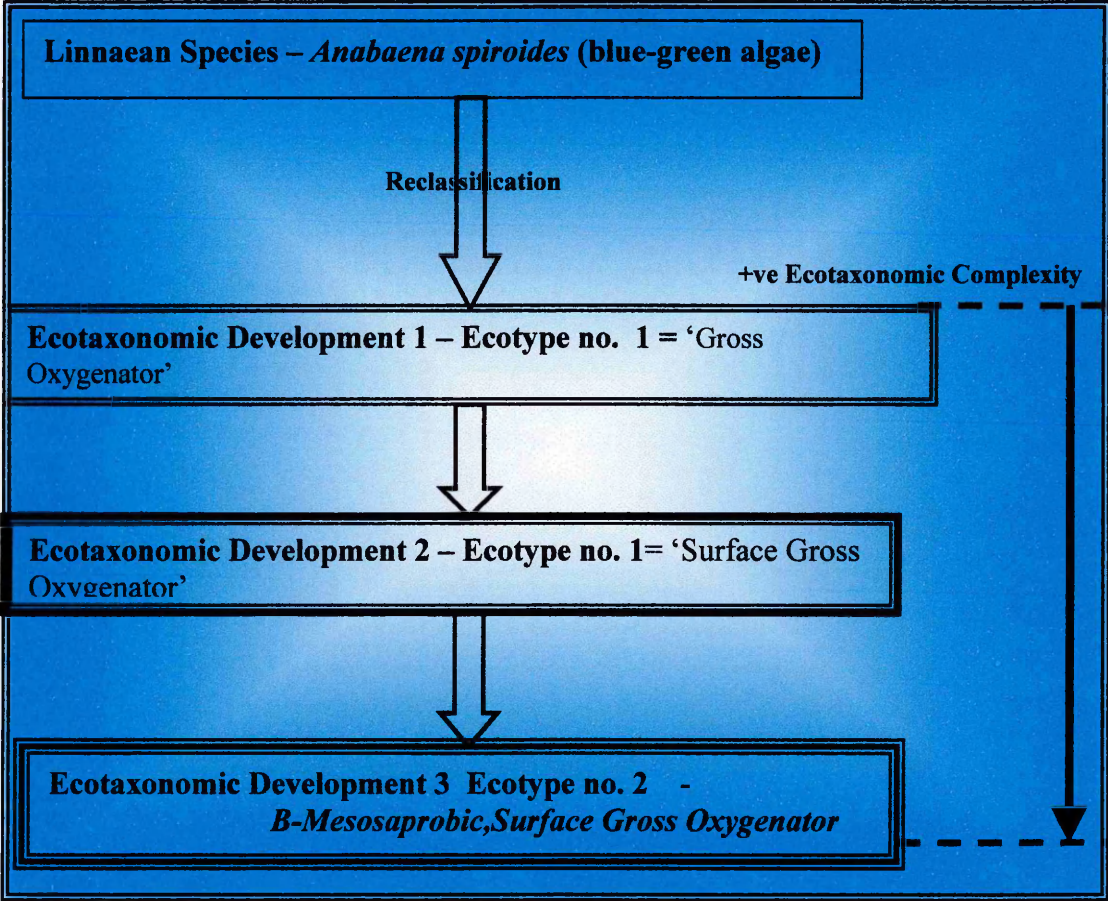
At the same time seasonal 'blooms' of blue-green algae species (caused by overloading systems with nutrients) are associated with the eutrophication of waterways, which reduces levels of dissolved oxygen and leads to the subsequent 'Suffocation' of other species. Cyanobacteria can also be associated with odour. There is, therefore a sensitive balance between certain algal species useful ecological engineering functionality and unhelpful potential to pollute.

2. The animal example uses *Keratella cochlearis*, this is a pelagic* rotifer* (small member of zooplankton*). Rotifers are found predominately in waters of low organic content, as they are aerobes, which generally require quite high levels of dissolved oxygen. Their diet consists primarily of bacteria and algae, but may also include small organic particles. Depending on the species of rotifer they can either remove these organics directly or indirectly via the consumption of other organisms from the water column or bed.

9.5.2 Reclassificatory Examples

Fig. 9.1 Two Examples (Plant and Animal) of Reclassifying the Biological Data

- i) The reclassification of a blue-green algae *Anabaena spiroides* using the Ecotaxonomy



ii) The reclassification of a rotifer *Keratella cochlearis* using the Ecotaxonomy

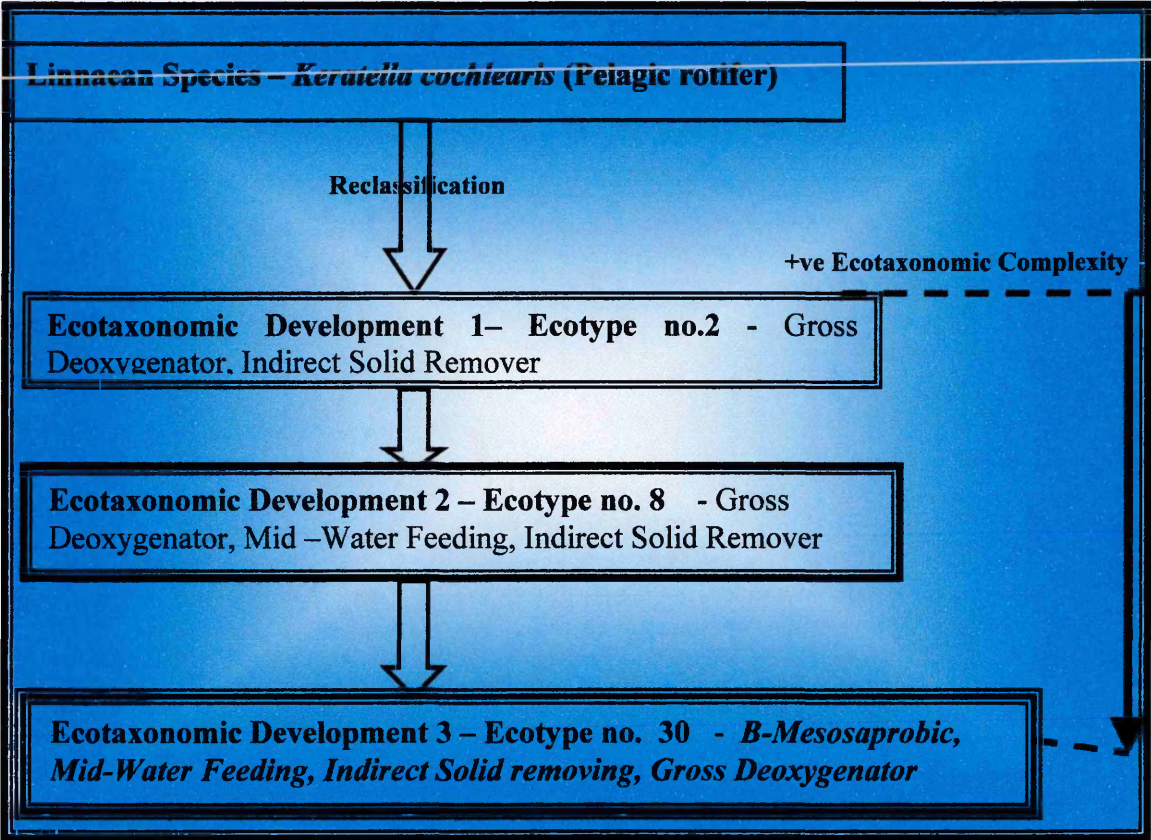


Table 9.3 Extract of the Databases showing the Reclassification of Organisms as ‘Ecotypes’

Common/ Group Name	Genus	Species	Ecotaxon (1)	Ecotaxon (2)	Ecotaxon (3) Ecotype
Blue-Green Algae	Anabaena	spiroides	1	1	2
Rotifera	Asplanchna	amphora	2	5	18
Rotifera	Keratella	cochlearis	2	5	18
Rotifera	Lecane	hamata	2	4	14
Crustacea	Daphnia	hyalina	2	5	18
Crustacea	Cyclops	Naupliua	2	6	22
Annelid (worm)	Tubifex	tubifex	2	4	16
Pisces (Fish)	Cyprinus	carpio	3	7	27
Chlorophyta Green Algae	Chodatella	ciliatia	1	1	2

The complete databases detailing the reclassification of organisms from the “Little Rock” and the two “Hungarian” studies can be found on Tables 7,8 and 9 in the appendices. The following tables, 9.4, 9.5 and 9.6 show an overview of ecotypes (as defined via the three ecotaxonomic stages) present in each system and shows the number of Linnaean taxa (generally species though sometime genus) which are reclassified as each of these ecotaxon.

Table 9.4 Overview: Reclassification of Data from the “Hungarian” Case Study 1971

<u>Ecotaxa Present in the System, Number and Description</u>	<u>No. of Linnaean Species Re-classified as Ecotaxa/Ecotypes</u>
2- B- Mesosaprobic, surface, gross oxygenator/algae	110
3 -A- Mesosaprobic,surface, gross oxygenator/algae	4
13 -Oligosaprobic,benthic-feeding,direct-solid-removing,gross-deoxygenator	1
14- B-Mesosaprobic,benthic-feeding,direct-solid-removing,gross-deoxygenator	22
15 -A-Mesosaprobic,benthic-feeding,direct-solid-removing,gross-deoxygenator	1
16 -Polysaprobic,benthic- feeding, direct-solid-removing, gross-deoxygenator	1
18- B- Mesosaprobic,midwater-feeding,direct-solid-removing,gross-deoxygenator	38
19- A-Mesosaprobic,midwater-feeding,direct-solid-removing,gross-deoxygenator	1
20- Polysaprobic,midwater-feeding,direct- solid -removing, gross -deoxygenator	1
22- B- Mesosaprobic,surface-feeding, direct-solid-removing, gross-deoxygenator	16
26- B-Mesosaprobic, benthic-feeding,indirect-solid-removing,gross-deoxygenator	2
27- A-Mesosaprobic, benthic-feeding,indirect-solid-removing,gross-deoxygenator	3
30- B-Mesosaprobic,midwater-feeding,indirect-solid-removing,gross-deoxygenator	4
Total = 204	

Graph to Show the Relationship Between Biological Variety (Linnaean Species) and Ecofunctional Diversity (Ecotaxa)-Hungarian Case-Study 1971

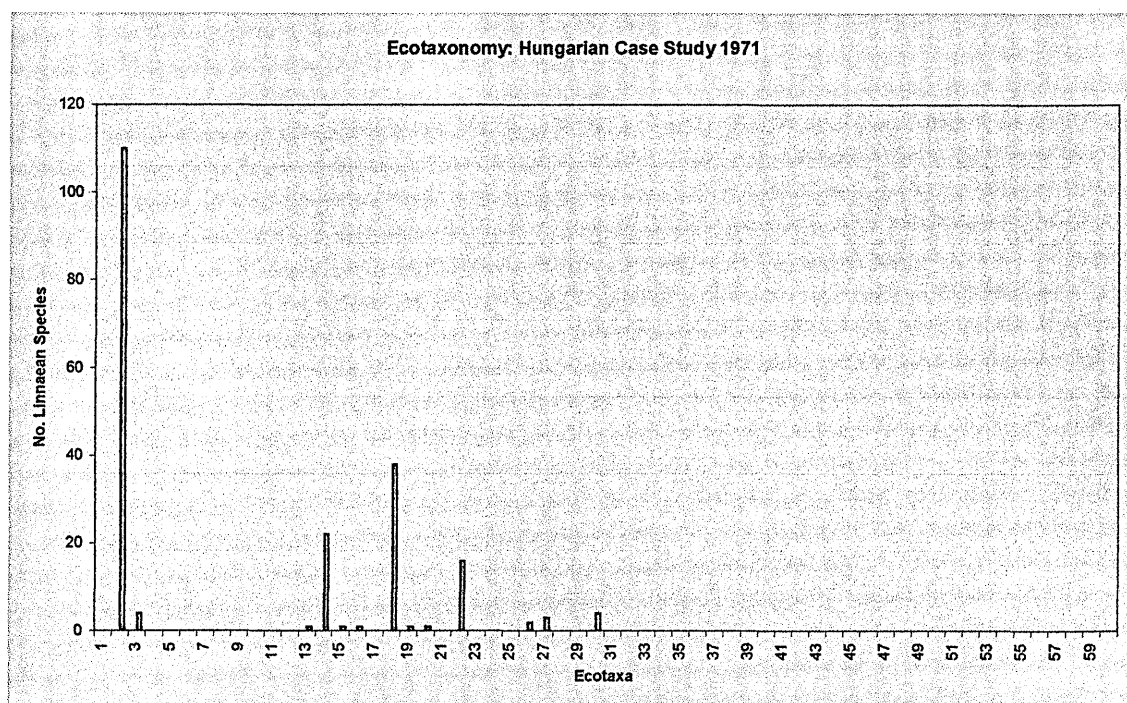


Table 9.5 Overview: Reclassification of data from the “Hungarian” Case Study 1972

<u>Ecotaxa Present in the System, Number and Description</u>	<u>No. of Linnaean Species Re-classified as Ecotaxa/ Ecotypes</u>
2- B- Mesosaprobic, surface, gross oxygenator/algae	131
3 -A- Mesosaprobic,surface, gross oxygenator/algae	4
14- B-Mesosaprobic,benthic-feeding,direct-solid-removing,gross-deoxygenator	16
16 -Polysaprobic,benthic- feeding, direct-solid-removing, gross-deoxygenator	2
18- B- Mesosaprobic,midwater-feeding,direct-solid-removing,gross-deoxygenator	36
19- A-Mesosaprobic,midwater-feeding,direct-solid-removing,gross-deoxygenator	1
22- B- Mesosaprobic,surface-feeding, direct-solid-removing, gross-deoxygenator	11
26- B-Mesosaprobic, benthic-feeding,indirect-solid-removing,gross-deoxygenator	2
27- A-Mesosaprobic, benthic-feeding,indirect-solid-removing,gross-deoxygenator	2
30- B-Mesosaprobic,midwater-feeding,indirect-solid-removing,gross deoxygenator	1
Total = 206	

Graph to Show the Relationship Between ‘Biological Variety’ (Linnaean Species) and Ecofunctional Diversity (Ecotaxa) – Hungarian Case-Study 1972

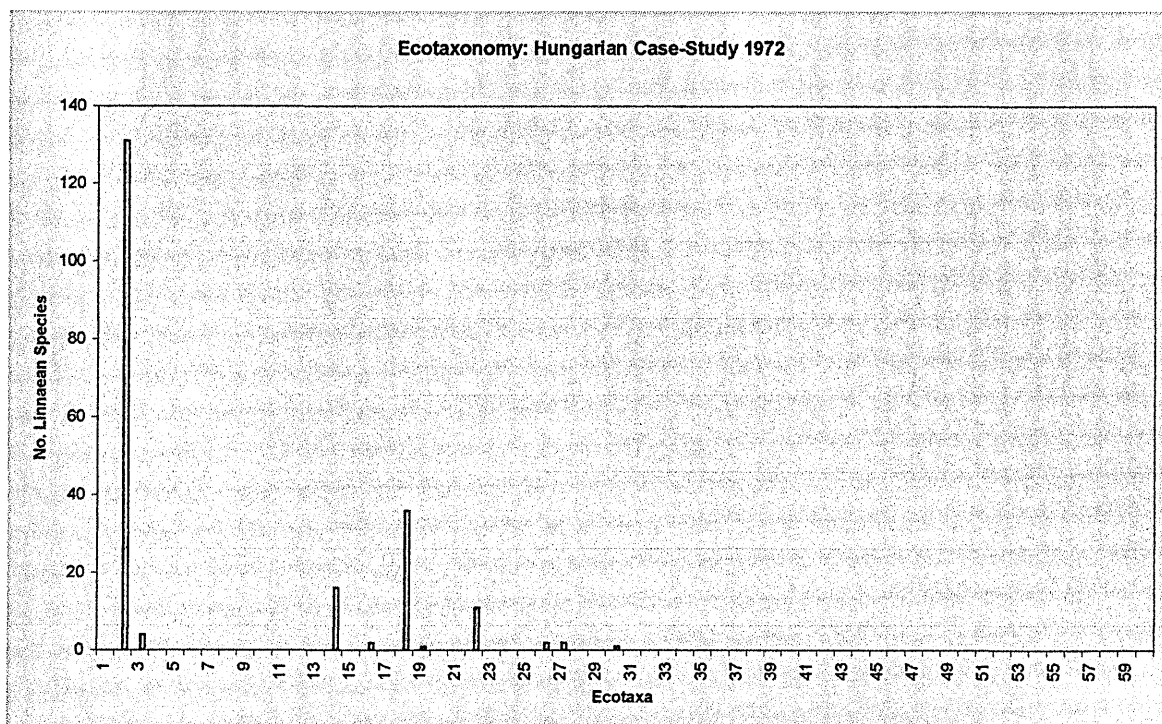


Table 9.6 Overview: The Reclassification of Data from the “Little Rock” Case Study

Ecotaxa Present in the System, Number and Description	No. of Linnaean Species Re-classified as Ecotaxa/Ecotypes
2- B- Mesosaprobic, surface, gross oxygenator/algae	57
3 -A- Mesosaprobic,surface, gross oxygenator/algae	2
13-Oligosaprobic, benthic-feeding,direct-solid-removing,gross-deoxygenator	1
14- B-Mesosaprobic,benthic-feeding,direct-solid-removing,gross-deoxygenator	43
26- B-Mesosaprobic, benthic-feeding,indirect-solid-removing,gross-deoxygenator	36
29-Oligosaprobic,midwater-feeding,indirect-solid-removing, gross-deoxygenator	1
30- B-Mesosaprobic,midwater-feeding,indirect-solid-removing,gross deoxygenator	35
34- B- Mesosaprobic,surface-feeding, indirect-solid-removing, gross deoxygenator	1
Total = 176	

Graph to Show the RelationshipBetween ‘Biological Variety’ (Linnaean Species) and Ecofunctional Diversity (Ecotaxa) – The ‘Little Rock’ Case Study

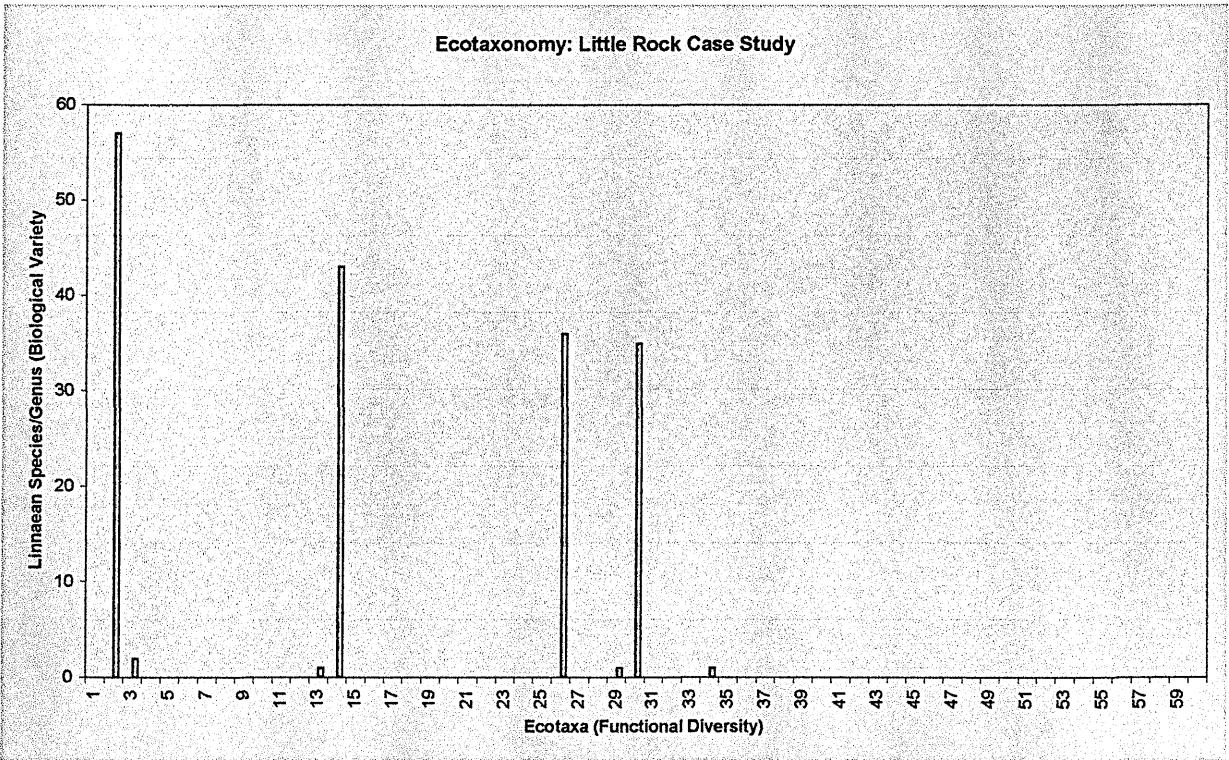


Table 9.7 Data Summary

Data Type	"Hungarian Study 1971"				"Hungarian Study 1972"				"Little Rock Study"			
Saprobic	PS	AS	BS	OS	PS	AS	BS	OS	PS	AS	BS	OS
Ectaxon:	16	3	2	13	16	3	2			3	2	13
	20	15	14			19	14				14	29
		19	18			27	18				26	
		27	22				22				30	
			26				26				34	
			30				30					
No. Linnaean per Ecotaxon above	1	4	110	1	2	4	131			2	57	1
	1	1	22			1	16				43	1
		1	38			2	36				36	
		3	16				11				35	
			2				2				1	
			4				1					
Position	B	MW	S		B	MW	S		B	MW	S	
Ecotaxon:	13	18	2		14	18	2		13	29	2	
	14	19	3		16	19	3		14	30	3	
	15	20	22		26	30	22		26		34	
	16	30			27							
	26											
	27											
No. Linnaean per Ecotaxon above	1	38	110		16	36	131		2	1	57	
	22	1	4		2	1	4		43	35	2	
	1	1	16		2	1	11		36		1	
	1	16			2							
	2											
	3											
Oxygen Stat.	Deox		Ox		Deox		Ox		Deox		Ox	
Ecotaxon:	13	19	2		14	22	2		13	29	2	
	14	20	3		16	26	3		14	30	3	
	15	22			18	27			26	34		
	16	26			19	30						
	18	27										
		30										
No. Linnaean per Ecotaxon above	1	1	110		16	11	131		1	1	57	
	22	1	4		2	2	4		43	35	2	
	1	16			36	2			36	1		
	1	2			1	1						
	38	3										
		4										
Solid Rem.	Direct		Indirect		Direct		Indirect		Direct		Indirect	
Ecotaxon	13	18	26		14	19	26		13		26	
	14	19	27		16	22	27		14		29	
	15	20	30		18		30				30	
	16	22									34	
No. Linnaean per Ecotaxon above	1	38	2		16	1	2		1		36	
	22	1	3		2	11	2		43		1	
	1	1	4		36		1				35	
	1	16									1	

KEY for Abbreviations:
PS-Polysaprobic, AS-Alpha-mesosaprobic, BS-Beta-mesosaprobic, OS-Oligosaprobic, B-Benthic, MW-Midwater, S-Surface
Deox-Gross deoxygenator, Ox-Gross Oxygenator, Oxygen Stat-Oxygen Status, Solid Rem.- Solid Removal

9.6 Discussion: The Reclassification Exercise

9.6.1. Patterns of Abundance

When the Linnaean specific types (species and genres) are reclassified using the ecotaxonomy, and the original biological variety is subsequently plotted against this new ecofunctional diversity (Ecotaxa), then several patterns emerge.

The most fundamental observation is that ecotaxa are always outnumbered by the Linnaean specific types. This is an obvious statement given that the number of species in the case-study systems always exceeds the maximum possible ecotaxonomic number of sixty ecotypes. Less obvious and more interesting are the patterns of abundance when different Linnaean species are allocated an ecotaxonomic niche.

It could be anticipated that, a maximum, of 15/60 i.e. only a quarter of the possible ecotaxa (ecotypes) could be identified as the system itself would dictate the saprobity (tolerance to BOD) of the organisms present and thus would restrict the ecotypes. Although all of the case studies identified less than 15 ecotaxa they were not representative of a single saprobic state. Aquatic systems are not however of uniform water quality. Levels of biochemical oxygen demand can vary depending both on lateral position and depth.

The highest numbers of organisms (biological variety) were associated with mesosaprobic conditions. With the vast majority being surface, beta-mesosaprobic associates. In all three case-studies the greatest number of species i.e. the greatest biological variety occurs within the single ecotaxon represented by Beta-mesosaprobic algae namely Ecotaxon 2; the B-Mesosaprobic, surface, gross oxygenators. Other non-algal groups also formed part of the B-Mesosaprobic component. These included benthic, midwater and surface feeders both direct and indirect solid removers i.e. a comprehensive ecofunctional representation.

The second largest B-Mesosaprobic component after the algae comprised in both the 'Hungarian' studies Ecotaxon 18; the midwater feeding direct solid remover, whilst in the 'Little Rock' study after the B-Mesosaprobic algal component it was the ecotaxon 14; the benthic feeding, direct solid remover which had the highest representation of Linnaean types. This Ecotaxon 14; the benthic feeding, direct solid remover actually featured heavily in the 'Hungarian' studies as well being the third largest B-Mesosaprobic component after the algae. The third largest B-Mesosaprobic in the 'Little Rock' study was Ecotaxon 26; the benthic- feeding, indirect-solid remover which just featured one species more than Ecotaxon 30; the midwater-feeding, indirect-solid remover in the 'Little Rock' study. Ecotaxon 22 the surface feeding, direct solid remover also exhibited high levels of biological diversity (16 and 11 species in 1971 and 1972 respectively) in the Hungarian study and was the ecotaxon with the fourth highest Linnaean representation.

The A-Mesosaprobic associated species (biological variety) were less numerous than the B-Mesosaprobic types in all three data sets. These represent organisms with

higher tolerance to BOD than the B-Mesosaprobic types detailed previously and were divided amongst the following ecotaxa:

- ◆ In the “Hungarian” 1971 case study a –Mesosaprobic ecotaxa: (3) surface, gross oxygenator/algae; (15) benthic-feeding, direct solid removing, gross-deoxygenator; (19) midwater-feeding, direct solid removing, gross-deoxygenator; (27) benthic-feeding, indirect solid removing, gross-deoxygenator.
- ◆ In the “Hungarian” 1972 case study A –Mesosaprobic ecotaxa: (3) surface, gross oxygenator/algae; (19) midwater-feeding, direct solid removing, gross-deoxygenator; (27) benthic-feeding, indirect solid removing, gross-deoxygenator.
- ◆ In the “Little Rock” case study a –Mesosaprobic ecotaxa: (3) surface, gross oxygenator/algae.

It can be seen from the above that the organically loaded “Hungarian” system was identified as containing more of the a –Mesosaprobic ecotaxa than the “Little Rock” lake system which contained only small one such ecotaxon, the A –Mesosaprobic algal type. This supports the fact that the “Little Rock” site was not being used as a wastewater treatment facility.

Oligosaprobic and Polysaprobic types are found in areas of very low and very high organic pollution, respectively (Table 6.6) and thus ecotaxa classified as either of these were rare in all three data sets. When they did occur the biological variety of each ecotaxon (ecotype) i.e. the number of Linnaean specific types was very low.

Oligosaprobic ecotaxa occurred in:

- ◆ The “Hungarian” 1971 case study once; Ecotaxa (13) Oligosaprobic, benthic-feeding, direct-solid-removing, gross-deoxygenator.
- ◆ The “Little Rock” case study, two ecotaxa were present, each reclassifying just one Linnaean species; Ecotaxa (13) Oligosaprobic, benthic-feeding, direct-solid-removing, gross-deoxygenator and (29) Oligosaprobic, mid-water-feeding, indirect-solid-removing, gross-deoxygenator.

Oligosaprobic ecotaxa were not identified in the “Hungarian” 1972 case study.

At the other end of the saprobic continuum Polysaprobic ecotaxa were identified:

- ◆ Twice in the “Hungarian” 1971 case study; (16) Polysaprobic, benthic-feeding, direct-solid-removing, gross-deoxygenator and (20) Polysaprobic, midwater-feeding, direct-solid-removing, gross-deoxygenator. Both exhibited low levels of biological variety comprising only one Linnaean specific type.
- ◆ Once in the “Hungarian” 1972 case study; (16) Polysaprobic, benthic-feeding, direct-solid-removing, gross-deoxygenator. Two Linnaean specific types were reclassified as this ecotaxon.

- ◆ Polysaprobic ecotaxa are not identified in the “Little Rock” case study

This situation reflects that the “Little Rock” system was relatively unpolluted by organic loading.

When vertical position is investigated the following patterns emerge:

- ◆ In the “Hungarian” 1971 case studySurface dwelling feeders/photosynthesizers are the least represented in terms of ecofunctionality with just three ecotaxa represented. This bellies the fact out that these three ecotaxa contain relatively high levels of biological variety i.e 130/204 sampled types:

Table 9.8 Surface Dwelling Biodiversity for “Hungarian” 1971 Study

Surface Dwellers;Ecotaxa:	Biological variety (No of Species)
(2) B-Mesosaprobic, surface, gross oxygenator/algae	110
(3) A- Mesosaprobic, surface, gross oxygenator/algae	4
(22) B-Mesosaprobic, surface-feeding,direct-solid-removing, gross-deoxygenator	16

Midwater feeders are represented by four ecotaxa but these reclassify less biological variety than for the surface dwelling types:

Table 9.9 Midwater Feeding Biodiversity for “Hungarian” 1971 Study”

Midwater feeders;Ecotaxa	Biological variety (No of Species)
(18) B- Mesosaprobic,midwater-feeding,direct-solid-removing,gross-deoxygenator	38
(19) A Mesosaprobic,midwater-feeding,direct-solid-removing,gross-deoxygenator	1
(20) Polysaprobic ,midwater-feeding,direct-solid-removing,gross-deoxygenator	1
(30) B- Mesosaprobic,midwater-feeding,indirect-solid-removing,gross-deoxygenator	4

Benthic feeders represent the highest levels of ecofunctionality but lowest biological variety;

Table 9.10 Benthic Feeding Biodiversity for “Hungarian” 1971 Study”

Benthic feeders;Ecotaxa	Biological variety (No of Species)
(13) Oligosaprobic, benthic-feeding, direct-solid-removing, gross-deoxygenator	1
(14)B-Mesosaprobic, benthic-feeding, direct-solid-removing, gross-deoxygenator	22
(15)A-Mesosaprobic, benthic-feeding, direct-solid-removing, gross-deoxygenator	1
(16)Polysaprobic, benthic-feeding, direct-solid-removing, gross-deoxygenator	1
(26)B-Mesosaprobic, benthic-feeding, indirect-solid-removing, gross-deoxygenator	2
(27)A-Mesosaprobic, benthic-feeding, indirect-solid-removing, gross-deoxygenator	3

◆ In the “Hungarian” 1972 case study

Surface dwelling feeders/photosynthesizers are represented by three ecotaxa. These three ecotaxa contain relatively high levels of biological variety i.e. 146/206 sampled types:

Table 9.11 Surface Dwelling Biodiversity for “Hungarian” 1972 Study

Surface Dwellers;Ecotaxa:	Biological variety (No of Species)
(2) B-Mesosaprobic, surface, gross oxygenator/algae	131
(3) A- Mesosaprobic, surface, gross oxygenator/algae	4
(22) B-Mesosaprobic, surface-feeding,direct-solid-removing, gross-deoxygenator	11

Midwater feeders are also represented by three ecotaxa but these reclassify less biological variety than for the surface dwelling types:

Table 9.12 Midwater Feeding Biodiversity for “Hungarian” 1972 Study”

Midwater feeders;Ecotaxa	Biological variety (No of Species)
(18) B- Mesosaprobic,midwater-feeding,direct-solid-removing,gross-deoxygenator	36
(19) A Mesosaprobic,midwater-feeding,direct-solid-removing,gross-deoxygenator	1
(30) B- Mesosaprobic,midwater-feeding,indirect-solid-removing,gross-deoxygenator	1

Benthic feeders represent the highest levels of ecofunctionality but lowest biological variety;

Table 9.13 Benthic Feeding Biodiversity for “Hungarian” 1972 Study”

Benthic feeders;Ecotaxa	Biological variety (No of Species)
(14)B-Mesosaprobic, benthic-feeding, direct-solid-removing, gross-deoxygenator	16
(16)Polysaprobic, benthic-feeding, direct-solid-removing, gross-deoxygenator	2
(26)B-Mesosaprobic, benthic-feeding, indirect-solid-removing, gross-deoxygenator	2
(27)A-Mesosaprobic, benthic-feeding, indirect-solid-removing, gross-deoxygenator	2

◆ In the “Little Rock” Case Study

Surface dwelling feeders/photosynthesizers are represented by three ecotaxa. These three ecotaxa contain just under a third of the biological variety identified i.e. 60/176 sampled types;

Table 9.14 Surface Dwelling Biodiversity for the “Little Rock” Study

Surface Dwellers;Ecotaxa:	Biological variety (No of Species)
(2) B-Mesosaprobic, surface, gross oxygenator/algae	57
(3) A- Mesosaprobic, surface, gross oxygenator/algae	2
(34) B-Mesosaprobic, surface-feeding,indirect-solid-removing, gross-deoxygenator	1

Midwater feeders are represented by just two ecotaxa and these reclassify less biological variety than for the surface dwelling types:

Table 9.15 Midwater Feeding Biodiversity for the “Little Rock” Study

Midwater feeders;Ecotaxa	Biological variety (No of Species)
(29) Oligosaprobic, midwater-feeding,indirect-solid-removing,gross deoxygenator	1
(30) B- Mesosaprobic,midwater-feeding,indirect-solid-removing,gross-deoxygenator	35

Benthic feeders represent the same levels of ecofunctionality as for Surface dwellers but have a much higher biological variety i.e.80/179 sampled types. When compared to Midwater and surface feeder, Benthic feeders represent the largest biological variety;

Table 9.16 Benthic Feeding Biodiversity for the “Little Rock” Study

Benthic feeders;Ecotaxa	Biological variety (No of Species)
(13)Oligosaprobic, benthic-feeding, direct-solid-removing, gross-deoxygenator	1
(14)B-Mesosaprobic, benthic-feeding, direct-solid-removing, gross-deoxygenator	43
(26)B-Mesosaprobic, benthic-feeding, indirect-solid-removing, gross-deoxygenator	36

The 1971 “Hungarian” study exhibits the highest level of ecofunctionality i.e has the most ecotaxa, 13 defined which reclassify 204 Linnaean specific types.

The 1972 “Hungarian” study exhibits the highest level of biological variety 206 Linnaean specific types are reclassified but these are representative of less ecofunctionality than the 1972 study with only 10 ecotaxa being identified. The relatively undisturbed system, in term of organic loading at “Little Rock” exhibits the lowest ecofunctionality, only 8 ecotaxa were identified and these clasified a total of 176 Linnaean specific types. In this way each ecotaxon contains a higher level of biological variety. The relevance of the lower ecofunctionality and biodivdersity found in the control/undisturbed systems is explore further in the next section.

In both “Hungarian” case studies one of the Polysaprobic types identified was benthic. This could indicate a relationship between saprobic conditions and position in benthos or water column. This idea is developed in the next section looking at the significance of the patterns revealed by the reclassification exercise.

In the “Little Rock” system it was the benthic eocfunctional type which were representative of the largest biological variety whereas in the “Hungarian” system the highest biological variety was reserved for surface dwelling eocfunctional types.

9.6.2 Significance of the Patterns

From the previous section it is clear that the greatest number of Linnaean specific types (biological variety) present in both case studies and three data sets were beta-mesosaprobic and these were mostly functionally classified as ecotaxon 2; the B-Mesosaprobic, surface, gross oxygenators. This is because the ecotaxonomy does not, at present, differentiate between different algal groups apart from providing four divisions according to saprobic conditions. Although algae tend to sink, because of light requirements, their functional activity, photosynthesis, occurs close to the surface and so they are classified according to this active position in the water column. The next most commonly occurring reclassified B-Mesosaprobic ecotaxa (in terms of numbers of Linnaean species) were midwater feeders for the Hungarian studies and benthic feeders for the Little Rock study. Those found to operate in the mid-water position tended to remove BOD in the form of suspended solids directly from the water column i.e. feed on organic debris, algae (phytoplankton) and bacterial remains.

Ecological hypotheses indicate that the primary producers of a system i.e. the plant component (which in aquatic systems is often comprised mainly of algae species) will always exceed the biomass of the animal component. There is a biomass decrease between subsequent trophic levels. (See trophic pyramid 7.3). This may have led to algae being the more prominent organism type in the system and thus most easily sampled. Paradoxically often the more diverse (in terms of species variety) the ecosystem the fewer individuals there are representing each species which would make such sampling more difficult.

Ecotaxa not represented by any of the systems include those representing macrophyte and air-breathing/gulping components. This is because these organisms were not recorded in the secondary data. This could be a reflection of the actual system or simply due to identification difficulties.

The lack of higher air breathing organisms such as such as Lepidosteidae fish (gars) and lungfish orders relates to the permanency of the water bodies described and the lack of need for such aestivation devices. The lack of air breathing larvae sampled in surface water may be the result of temporality of sampling. This surface air breathing/gulping component does not include the functionality of emergent plants whilst respiring at night as it is the plants ‘gross oxygenators’ functionality in the water column which is of primary interest.

All four saprobic types were recorded in the data and were actually identified inhabiting the same pond system in the 1971 "Hungarian" case study. In this case sampling took place laterally from wastewater inflow to outflow so it is likely that any polysaprobic organisms would congregate round the former whilst beta-mesosaprobic or even oligosaprobic organisms would be found at the latter. In addition, apart from organisms which are used traditionally as indicator species very few species are totally restricted to the single saprobic zone where they predominate. Also the demarcation between changing water quality zones is not always sudden.

Water quality can also vary with depth which relates to an organisms position in the water column e.g. the water near to the bottom of the lake is likely to be toward the polysaprobic end of the saprobien scale when anaerobic conditions prevail in the benthos* and can via the fermentation of plant deposits (cellulose) in the mud generate hydrogensulphide from sulphate ions. Closer to the surface which is the region of natural aeration via mixing and simple gaseous transfer than the water quality would be likely to be in the mesosaprobic range. In this way there could be correlation between how organisms are classified by their position in the water column and what saprobic type they are.

The co-existence of the four saprobic types in this way was not completely representative of the organic state of the system because the predomination of B-Mesosaprobic types was marked indicating only low grade pollution (table 6.5). The A-Mesosaprobic associated species (biological variety) were much less numerous The occurrence of indicators of extreme pollution (Polysaprobic types) or clean conditions (Oligosaprobic) were very low. If a system was subjected to constant high organic loading than polysaprobic conditions would prevail throughout and only organisms associated with such anoxic conditions would survive i.e. only a possible 15/60 of the ecotaxa. In this way it is useful to have a system of low to moderate organic pollution as this enables studies to be carried out on a higher number of ecotaxa and patterns of pollution dispersion can be traced through the water column and with distance from the loading source.

The potential 30 taxa associated with indicators of polysaprobic and oligosaprobic conditions were hardly represented i.e. there was little chance of 30/60 ecotaxa being present. This was born out by the fact that:

- ◆ Only one oligotrophic associate (one Linnaean species reclassified as an ecotaxon 13; Oligosaprobic, benthic-feeding, direct-solid-removing-gross-deoxygenator) was found to be present in the 1971 "Hungarian" case study and two (two Linnaean species reclassified as two ecotaxa: ecotaxon 13; Oligosaprobic, benthic-feeding, direct-solid-removing-gross-deoxygenator and ecotaxo 29; Oligosaprobic, midwater-feeding, indirect-solid-removing-gross-deoxygenator in the relatively unaffected "Little Rock" system.
- ◆ Only three polysaprobic associate ecotaxon were found in both "Hungarian " studies. In 1971 one Linnaean species was reclassified as ecotaxon 16: Polysaprobic, benthic-feeding, direct-solid-removing-gross-deoxygenator and one Linnaean species was reclassified as ecotaxon 20: Polysaprobic, midwater-

feeding,direct-solid-removing,gross-deoxygenator. Only one polysaprobic ecotaxon with two Linnaean species reclassified as a single ecotaxon ,16: (Polysaprobic, benthic-feeding,direct-solid-removing-gross-deoxygenator) was found to be present in the 1972 “Hungarian” case study. No such polysaprobic associates were found in the “Little Rock” system.

This lack of polysaprobic conditions would be expected in the natural lake system. It is notable that in both years the polysaprobic associate: Exotaxon 16,Polysaprobic, benthic-feeding,direct-solid-removing-gross-deoxygenator was present. This would relate to the fact that such polysaprobic conditions would be likely to occur in the benthos of the system where anaerobic conditions prevail and where organisms are likely to be detritivorous feeders feeding on the dead matter which sinks to the bottom.

The pattern of distribution does not change much between the two years tested in the Hungarian system. The three ecotaxa which are lost from the system between the years 1971 and 1972 are 13, oligosaprobic benthic feeding, direct solid removing, gross deoxygenator, 15, alpha-mesosaprobic benthic feeding, direct solid removing, gross deoxygenators and 20, polysaprobic midwater feeding direct solid removing, gross deoxygenator. Although it is interesting that the three ecotaxa which disappeared from the Hungarian system differ in their saprobity*, this could suggest that their disappearance was not as a result of a severe shift in the overall biochemistry of the system. However because of the low numbers of species involved this shift is more likely a simple result of the organisms evasiveness during sampling.

The following interesting patterns emerged from this taxonomic exercise

- ◆ At the highest taxonomic level despite the wide variety of organisms in terms of Linnaean species, functional diversity was sparsely represented. This is probably due to the exclusion of air breathing organisms and because the system was notably devoid of macrophyte identification. (Plans to include macrophytes were mentioned in the articles).
- ◆ The majority of Linnaean species comprising the systems variety were found in a single ecotaxon i.e. that of algae. The merit of splitting algae into further functional groups, according to species blooming capabilities, is being investigated as an extension of this research. Due to the absence of macrophytes algae represent singularly the plant (oxygenating component) of the system and as primary producers these form the majority of the biomass of the system (see Fig 3.4).
- ◆ The next most common ecotaxon, in the “Hungarian” studies, number 18 represented the beta-mesosaprobic, midwater feeding, direct solid removing, gross deoxygenators. This is because much of the zooplanktonic component (rotifers and crustaceans) fall into this category.

From the patterns of abundance it was also revealed that biodiversity, in terms of biological variety can be described by relatively few ecotaxa. This is because the ecotaxonomy uses fewer rules to split organisms into their functional groups. This means that;

- ◆ It would be possible to actually reduce species number and therefore biological variety whilst actually not reducing the number of ecotaxa in a system.
- ◆ It would be possible for another system to have greater biological variety whilst having fewer ecotaxa.

It is important that functional ecotaxa should not be confused with ecological niches.

“Each organisms has a special task in an ecosystem – known as a niche. No two species of plant or animal can occupy the same ecological niche for long; competition ensues and one species eventually adapts to occupy a different niche, or dies out” (Porteous, 1996).

The ecotaxonomy does not attempt to detail the ensemble of an organism's behavioural traits but concentrates purely upon those few context driven functional elements which pertain directly to appreciating an individual type as an interactive part of a functioning whole. In this way several species can fulfill the criteria set by a single ecotaxon.

In this way the ecotaxonomy is removed from conservationist ideals of 'Natural' systems and biodiversity (Chapter 10). This does not mean an ecotaxonomy could not be set up with conservationist ideals in mind and it might not necessarily replicate the Linnaea taxonomic system. It could, for instance, use modern phylogenetic techniques to 'lump' genetically similar organisms together and other classificatory parameters such as symbiotic relationships between organisms which ensure their mutual survival in a system.

The relevance of the lower ecofunctionality and biodiversity found in the control/undisturbed “Little Rock” system should not be overstated as this is probably more likely to be due to the original classification of organisms than founded in any real lack of biodiversity. This is because many of the organisms were only identified to genus level as opposed to species being identified as was the case, generally in the “Hungarian” studies. This meant that there appeared to be less comparable biological variety and subsequently, in this case less ecotaxa (although as was stated above this is not the general rule) than there actually might have been. It is difficult to estimate what effect this might have on the ecofunctional representation. Section 6.4 investigates how ecofunctional representation can differ dependant of the level of the Linnaean taxonomic hierarchy used. Paradoxically then, this interesting observation is an anomaly, related, to issues of 'taxonomic resolution' rather than any real system dynamics of ecological and water quality change.

9.6.3 Additional Taxa

It is unlikely that any set of food-web data will specify all the organisms and the interactions, which exist in a particular aquatic system. For instance most species in Little Rock Lake are probably benthic organisms such as micrometazoans* and other microbes. Unfortunately these microbial types are included in the data as a severely aggregated taxon termed 'fine organic matter'. This complex group of organism has

been found to include three hundred species in a small temperate lake in New Hampshire (Strayer and Likens, 1986 in Martinez, 1991). Members of such a microbial ecology would be likely to be associated with the micro-diversity (species and function) associated with traditional water treatment systems such as those found in activated sludge and trickle filter processes.

In order to test the use of the ecotaxonomy to identify patterns of functional abundance other data sets need to be used. These do not necessarily have to come from papers detailing other wastewater fed aquaculture systems. It would be interesting to find aquatic communities which include more of the sixty ecotaxa e.g. those which contain macrophytes as well as algae and air breathing organism such as lungfish.

By looking at other aquatic systems universal patterns of ecofunctional diversity may emerge. It is likely for instance that algae abundance will influence the variety of oxygen demanding benthic organisms and that the presence of surface macrophyte taxa will reduce algal variety and enhance epiphyte* variety.

It is also possible that further taxonomic division of the algae ecotaxon may be necessary to further reflect patterns of functional diversity. It is envisaged that algae could be divided into blooming and non-blooming forms. It would also be interesting to reclassify the data sets using an ecotaxonomy which uses other biotic indices section (10.5).

Ecofunctional diversity in this research can equate to the use of the term diversity in the ecological sciences when it is not simply the richness or the variety of Linnaean species found in various ecological locales which is being denoted but the degree to which different species enjoy equivalent functional representation.

Functional diversity can be thought of as the number of different functional categories defined in a context driven taxonomy which can be used to re-categorize the variety of physical components which represent the lowest level taxon defined in a well developed taxonomic hierarchy. Species diversity (defined as variety in this context) in stable ecosystems is closely linked to abundance of individual organisms. It is generally accepted that stable ecosystems are characterized by a great diversity of species, which are represented by relatively few individuals but this can actually be disputed (Section 4.3.1, 10.6). When an ecosystems stability is threatened by physical or chemical factors reducing the range of habitats or niches available this biodiversity (biological variety) abundance relationship is reversed i.e. high numbers of individuals represent relatively low numbers of species. The inflow of wastewater into a watercourse can bring about such reduced diversity as the increase in nutrients and reduced competition enables a few species to develop to high population densities. Having said that, slight pollution causing nutrient enrichment can result in enhanced species diversity although this may not always be considered ecologically desirable if, for instance, it results in additional species of blooming algae creating eutrophic conditions.

9.7 Strengths and Weaknesses of the Ecotaxonomic Exercise

The strengths of such context driven reclassificatory exercise can be summarized as:

- ◆ It identifies species in terms of their context driven ‘eco’functional abundance.
- ◆ It shows how manipulation of classification systems can be used to map between closely related disciplines.
- ◆ It leads to enhanced data analysis by revealing otherwise concealed patterns of distribution.
- ◆ Manipulating taxonomies adds another dimension to testing the integrity of traditional research activities.

During the taxonomic exercise certain research weaknesses were also revealed:

- ◆ Research frameworks are geared toward using traditional taxonomic systems and so the data required for reclassification is not always readily available.
- ◆ The ecotaxonomy attempts to integrate spatiality in terms of position and tolerance with ecofunctionality. This it could be argued is a rather artificial unification although it serves the purpose of identifying organisms in terms of where they can function which is in itself a component of their activity.
- ◆ The patterns revealed by the exercise indicate that the algal component of the ecotaxonomy requires further classificatory divisions.
- ◆ The use of the classification to identify patterns of functional abundance relies on a variety of species being identified in the system.
- ◆ Few species are restricted to a single saprobic zone and many revisions have been made to the saprobic index including the use of twenty saprobic values. In river systems the index is only used for classifying benthic organisms since planktonic organisms can reflect the situation upstream.
- ◆ The “Little Rock” case study’s “taxonomic resolution” is different to the “Hungarian” one i.e. organisms are often not classified to species level but only to genus giving a relatively skewed perception of the biological variety of the system.

The fact that two different aquatic systems exhibited very similar patterns of abundance of ecotaxa indicates not that they are identical in terms of their biological variety (biodiversity) but that:

- ◆ There are similar weaknesses when it comes to the collection of holistic data sets for such systems. For instance defining the system barriers and including emergent, littoral and commensalist organisms such as macrophytes and their attached epiphyte species.
- ◆ The ecotaxonomy still requires further development to allow greater ecotaxa differentiation.

These two are inextricably linked and are representative of the need, for practical system sampling to be carried out alongside the development of interdisciplinary methodologies such as ecotaxonomic frameworks, in order to collect 'relevant' data sets (Section 5.2.3)

9.8 Application of the New Taxonomy for the Design of 'natural' Systems for Water Treatment

The 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 solid 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).
- ◆ 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.

Identifying a set of strengths and weaknesses of the ecotaxonomic approach can help locate its potential application to 'real world' problems and suggest possible developments of the work itself.

The first point to note is that the ecotaxonomic approach attempts to classify an organism's ecofunctionality in terms of key transformations intrinsic to energy transfer (Chapter 7) by distinguishing between ecological interrelationships central to energy transfer.

Secondly, the approach facilitates the transfer of knowledge between the different fractions of the biological science 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 research raises questions about the skills required to support a more diverse strategy for water management.

"Water treatment via the control and regulation (harnessing) of an ecology requires knowledge and skills which are currently under represented in many water management institutions. The integration of zoologists, botanists and ecologists 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"
(Browne, Seaton and Jeffrey, 2000).

Weaknesses of such an ecotaxonomic approach include:

1. It's inability to operate in isolation of phylogenetic taxonomic systems such as the Linnaean binomial nomenclature or modifications of it (hence the cooperation between taxonomies in this research). Though in terms of interdisciplinary research this could metamorphose into a strength.
2. To a certain extent it also only represents a static picture of organism ecofunctionality.
3. Significantly, the ecotaxonomic approach is limited to context specific applications because an organism's ecofunctionality depends on the scale of the ecologically engineered system (its boundarised ecological complexity).
4. It gives no indication of density in terms of actual numbers of organisms identified and population sizes.
5. Organism position is restricted to its vertical distribution in terms of the water column and benthos. Lateral position from say, an organic loading outlet would also be a useful reclassifying parameter.

Examples of 2. above include the fact that 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.

A clear example of 3 is when the functionality being classified is restricted in the water column and benthos, in this case if a system includes 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.

A further examination of ecotaxonomic utility and development is detailed in Chapter 10.

Chapter 10.

The Research Implications, Utility and Limitations

10.1 Introduction

10.1.1 The Overall Objective

“A part of, not apart from nature” (Mitsch and Jørgensen, 1989)

This thesis has addressed the perceptual divide between humans observing nature and existing within natural systems (Chapter 1). The research argues that ‘natural’ system definitions need to include human physical and social attributes in addition to simply defining the biological and ecological processes which are generally perceived to comprise them.

In this way perceived human systems such as wastewater treatment need to be designed with these biological and ecological processes in mind, not only from an environmental impact or conservationist view-point but also from one which recognises the utility of such ‘natural’ processes within a human social context. Harnessing ecological processes is somewhat different from dominating them as the former allows for the concept of self-design or self-organization (Odum, 1988) and in the case of waste treatment self-purification.

“It is this self-designing capability of ecosystems that ecological engineering recognizes as a significant feature, because it allows nature to do some of the “engineering.” We participate as the choice generator and as a facilitator of matching environments with ecosystems, but nature does the rest” (Mitsch and Jørgensen, 1989)

The overall objective of the research was stated in Section 1.5 as:

- 1. To explore an ecotechnological, interdisciplinary approach to studying ‘natural’, in ecologically engineered terms, systems.**

The following sections reiterate the way in which this was done and detail the intellectual implications and limitations of the research.

10.1.2 Research Limitations

Natural systems are by definition complex (Allen, 1997) this means that any research involved in investigating natural systems will require a substantial level of simplification. It could be argued that the creation of the ecotaxonomy, and the preoccupation with a soft technological approach in terms of knowledge application, undervalues the relevance of hard technological and engineering concepts.

In Section 5.2.8 it was noted that the developing discipline of ecological engineering has been, and still continues to be, dominated with research of a 'hard' technical 'nature' as was more than apparent at the last International Ecological Engineering Conference "*Managing the Wastewater Resource: Ecological Engineering for Wastewater Treatment*" (ÅS, Norway June 7-11th 1999) where the research still seemed to be very much site specific and left to the attention of chemical engineers.

If ecological engineering (as ecotechnology), a developing synergetic technoscientific partnership is to gain descriptive credence as a scientific discipline, in the way in which, say biological engineering (biotechnology) has, it needs to develop a scientific nomenclature with which to assess the universality of its concepts. By merit of its close association with ecology as a scientific discipline it unfortunately inherits all the problematic and ambiguous concepts which accompany such a complex 'natural' science for example even defining 'ecosystems'* in any meaningful way is largely impossible.

Having said that, at least ecological principles such as trophic levels attempt to create a general classification of useful functionality. Although such classification systems are crude and thus often regarded as unrealistic, they do, however, serve a very important purpose, in that, they generate the interdisciplinary incentives to research processes and interactions. The ecotaxonomy has been developed using such crude and simplistic classificatory frameworks (namely trophic levels and the saprobic system) and is thus, itself, a simple and crude classificatory device. This in no way, however, detracts from its value in reassessing the way in which scientists perceive natural systems, especially when socially/ technologically directed. Given time, the basic ideas conceptualized in this research should provide some scope with which to develop ecotaxonomic frameworks with far greater utility.

10.2 Interdisciplinarity and Ecotechnology

The developing science of ecological engineering (Chapter 2) attempts to harness the utility of ecological processes in a way, which is beneficial to both human and non-human components of 'natural' systems.

"So ecological engineering is not a license to pollute, but human society and ecosystems are viewed as an entity. Ecological and holistic viewpoints are emphasized" (Mitsch and Jørgensen, 1989)

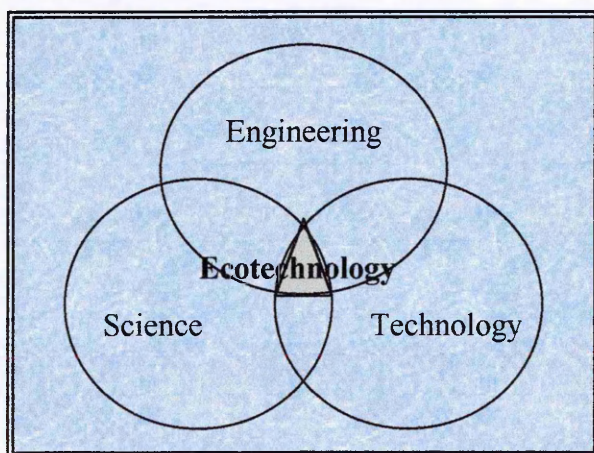
Presently ecological engineering still remains an example of a 'hard' technoscience and this research suggests that for it to develop holistically and become an example of 'ecotechnology' it requires in addition, the incorporation of a 'soft' technological (technos) approach in terms of 'applied knowledge'.

Ecological engineering emerges as a 'hard' technology from the combination of science and engineering praxis. As such it is not able to maximise the ecological self-designing principles which are found in those systems traditionally defined as 'natural', as it is simply representative of a system dependant on human-control. If, in addition, a soft technological approach is taken via an integrative use of the science

describing the physical system, then an ecotechnological level emerges (Fig.1.4, Fig 10.3)

The Science circle of the Venn diagram below incorporates all manner of scientific disciplines. Applying knowledge in a way useful to an ecological engineering context requires taking an interdisciplinary (Chapter 2) approach to utilise information from the different disciplines and sub-disciplines which describe the processes of interest. This interdisciplinarity can then be used to contribute to the hard technological and engineering aspects.

Fig 10.1 Ecotechnology



During the research design it became apparent that some sort of interdisciplinary framework was required to map between the organizational levels involved in the ‘natural’ processes contributing to the water treatment (Chapter 5).

This is concurrent with the second research objective:

2. To develop an assessment method for investigating the bi-directionality between water quality (biochemical) and ecological change as a socially directed biophysical or ‘natural’ technology.

To do this an innovative approach was taken in the form of developing an ‘inter’ taxonomic system or ecotaxonomy. This involved mapping key concepts taken from the classification systems traditionally associated with the appropriate biological sub-disciplines which allowed the biochemistry of the system to be mapped onto its ecology (Fig 10.3).

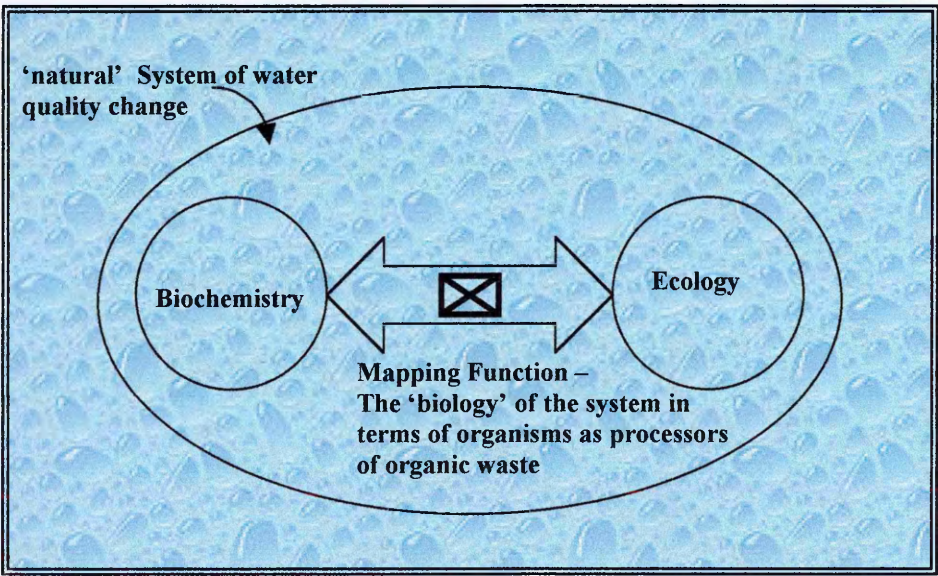
10.3 Mapping Functions

The concept of using “mapping functions” (Seaton, 2000) to facilitate knowledge translation between disciplines was detailed in Chapter1 (Section 1.4.2). Figure 1.3 showed how the biology of a system can be used to map biochemical and ecological

processes. This idea can then be extended to the concept of mapping the knowledge transfer system required to do this (Fig 10.3 b).

Figs. 10.2 a,b Biological Mapping Functions Real and Epistemological

a) Mapping the **process** of water quality change in a 'natural' system to show the biological component as the mapping function between the system's relevant biochemical and ecological state.

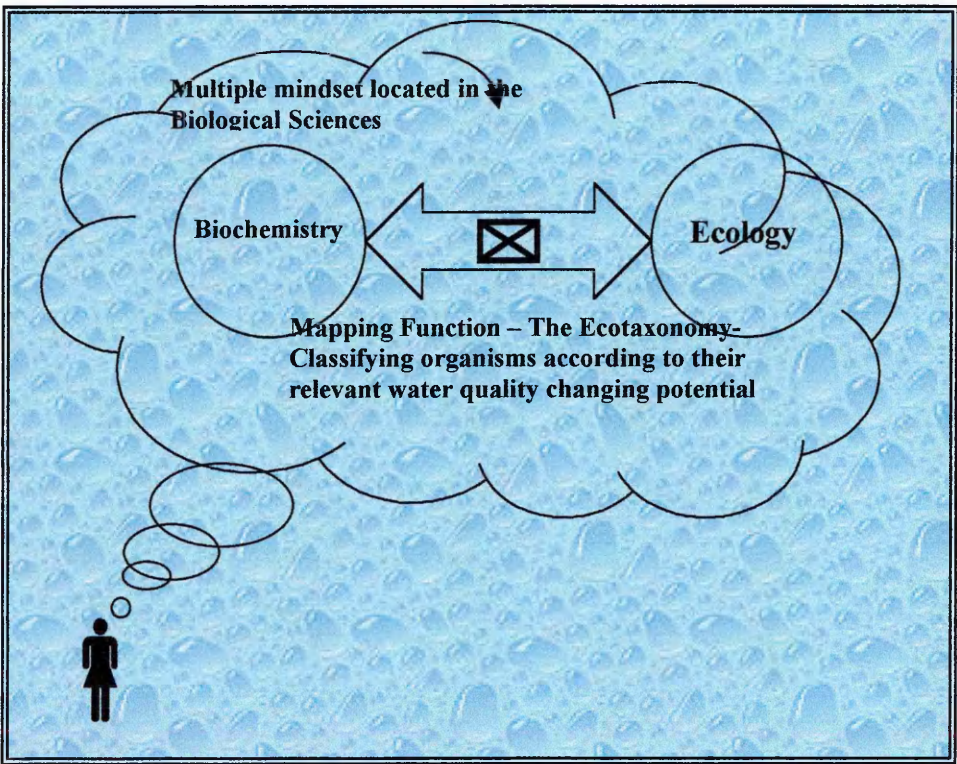


The mapping process was simplistically approached by taking an engineering approach to the classification of the systems biology i.e. by classifying according to context functionality rather than natural history.

Although organisms exist as evolutionary isolates in the system their individual contribution to the relevant treatment potential still relates to their functionality as group (ecological) members. By creating a new taxonomic system or ecotaxonomy (Chapter 8), which was to a certain extent a hybridization of traditional biological (Chapter 6) and ecological (Chapter 7) classification systems, this seemingly paradoxical situation of classifying individuals in terms of their group functionality was, to a certain extent, achieved.

Figure 10.2b) on the next page illustrates how the ecotaxonomy as a representation of the biology of the system becomes, as a mapping function, in effect, an epistemological tool for mapping the two knowledge domains. The ecotaxonomy also, at certain levels, can be perceived as mapping biological (Linnaean) and ecological (trophic) classification systems (Section 7.5).

b) Mapping the *knowledge transfer system* required for Fig 10.2 a)



10.4 Hierarchy and Emergence

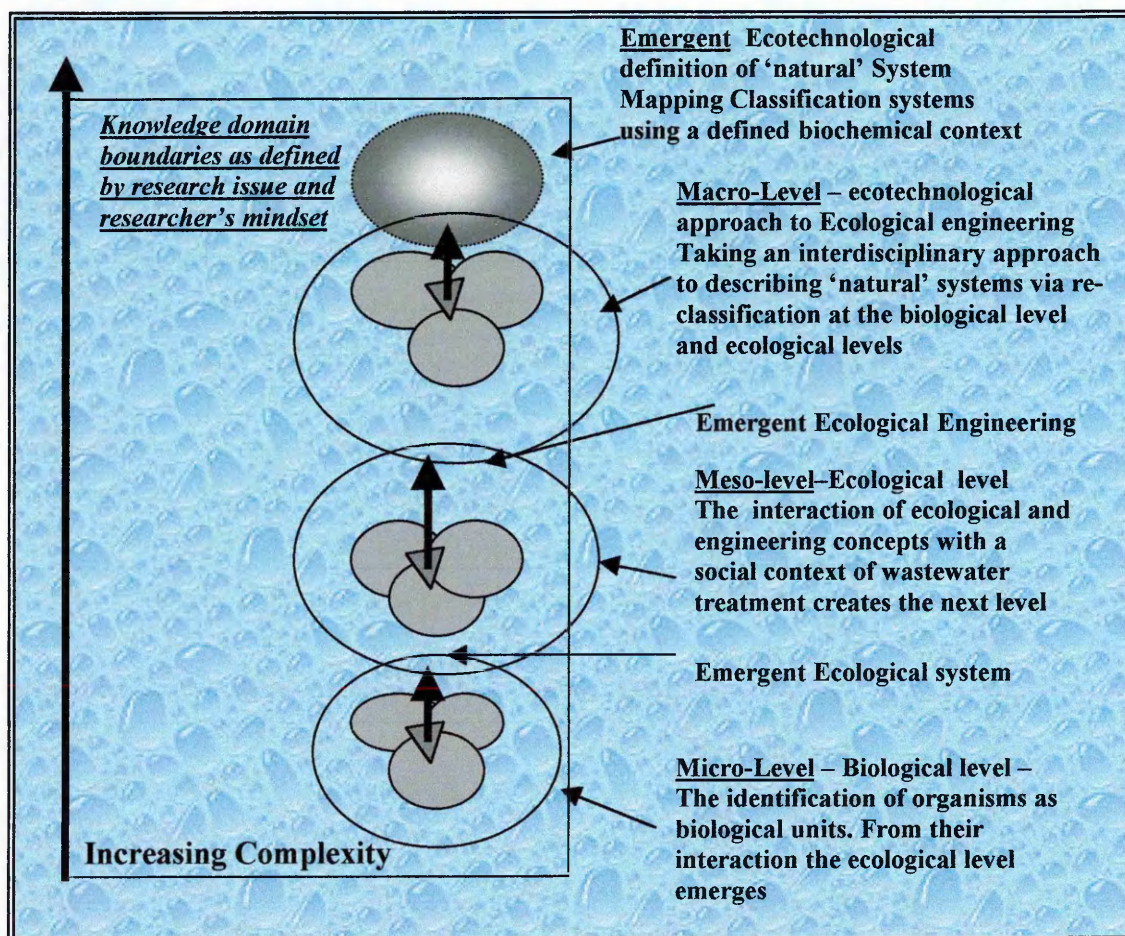
10.4.1 Re- ‘viewing’ Emergence

In Chapter 1, Figure 1.4 illustrated the concept of knowledge emergence from a ‘bottom-up researching’ approach. Figure 10.3 on the next page re-iterates this but acknowledges the interacting components and levels specific to this research. Each successive level can only be seen to emerge when taking a bottom-up approach to researching, as is the case in this thesis, but in order to appreciate the complexity of the system as a whole an overview is needed in the form of top-down recognition (Figure 1.5). This is not a vitalist perspective but simply one which can oversee the emergent self-organizing principals, whether these are real in the physical sense or simply epistemological tools for learning about such complexity.

The following diagram is not directly representative of the physical hierarchy (Chapter 5) central to this research comprising the nested biochemistry, biology and ecology of the treatment system. This is because it is illustrating the process of knowledge of emergence with respect to understanding physical systems. This is complicated by the fact that physical systems are comprised of numerous organizational levels. This research has, in a sense, used the concepts of hierarchy and emergence to illustrate systems which are, in the real sense, physically nested and thus reflective of physical hierarchies and emergence. This duality is difficult to represent simultaneously.

Fig 10.3 Hierarchical and Emergent Aspects Relevant to this Research

(Diagram format after Seaton and Hadfield ,1999)



10.4.2 Emergence and the Ecotaxonomy

The ecotaxonomic framework cannot incorporate the concept of biological evolution in terms of speciation* as it owes nothing to theories of natural selection* or punctuated equilibrium* etc. Also, unlike the Linnaean taxonomic system which classifies according to morphological similarity, it gives no indications of an organisms phylogeny*. It is, therefore, by no means, a natural classification in the traditional sense (Table 10.3) (Rainbow *per. com.* 1999). The objective of this research was not, however to develop a 'natural' taxonomy in the biological sense but

3. To develop a taxonomic framework (ecotaxonomy) which takes into account the concept of emergence in describing such 'natural' systems to allow for objective (interdisciplinary) classificatory adaptation according to the research focus.

The ecotaxonomy can, however, be adapted and thus is equipped to deal with the concept of emergence where unanticipated developments emerge from

interactions/associations at lower organizational levels. This capacity is, to a certain extent due to its non-hierarchical construction. It does not matter for instance whether an organism's saprophy is classified prior to its position in the water column or vice versa as one is not nested in the other.

Furthermore the ecotaxonomy is actually reflective of the process of physical emergence. This is because it classifies organisms (which are biochemical associations) according to the emergent phenomena which manifests itself as a result of their interactions i.e. the ecology (biological associations) of which they are a part.

10.5 Ecotaxonomic Utility

10.5.1 Ecotaxonomy and Ecological Engineering

The ecotaxonomy as a process of ecological engineering can be utilised to provide a framework for the collection of 'relevant data' (Chapter 5) or the use of existing data when the functionality of natural systems as a whole is being investigated. It provides a soft systems approach toward developing a useful issue-based research methodology.

The ecotaxonomy also presents an alternative viewing mechanism on the state of 'natural' systems by providing a different perspective of the biodiversity present; one which is related to a defined functionality of the system. It does not set out to provide a conclusive picture of the system as a whole but to be used as a tool for extracting useful/'relevant' data about processes of human concern.

This research has taken the idea of ecological engineering waste water treatment systems as an example of an interdisciplinary approach toward a complex techno-scientific issue located in a wider environmental policy setting. It has implications for:

- ◆ Using the components of natural systems as 'indicators' of change and vulnerability for open water systems generally.
- ◆ Taking the logic of mapping and using it not only to study other water treatment scenarios (since it is context dependant) but also to study other biological/ecological interactions such as; ecological farming, soil systems and even to human ecology and knowledge transfer systems.

By using in its development parameters relevant to water treatment processes the ecotaxonomy detailed in Chapter 8 and developments of it (especially if pertinent socio-economic data such as key farming parameters of potential yield and ease of harvest were included) could be used to suggest alternative organisms for wastewater-fed aquaculture systems.

Further developments of the ecotaxonomy developed in Chapter 8 could include:

- ◆ Further algae divisions as at the moment the ecotaxonomy tends to lead to 'clumping of algae into a singular undifferentiated group. An important

characteristic of different types of algae species with respect to water treatment is whether or not they have a tendency to bloom in eutrophic conditions. A simple addition to the ecotaxonomy would be to divide the algal component into 'blooming' and 'non' blooming ecotaxon or for added variety and functional diversity grades of 'blooming potential' could be classed.

- ◆ Using Aquaculture information such as that found in Table 4 of the Appendices 'stocking' categories could be added to the ecotaxonomic framework. This would bring the farming component into the taxonomic forum. Categories could even be used to define whether the produce is directly consumed by humans or by other farm animals or kept within the aquaculture system and used indirectly to feed the produce. This relates to section 4.6 and the harvesting of different trophic levels depending on social requirements of the physical system.
- ◆ Density measurements in terms of numbers of individuals of each species/genus and use this as a reclassifying parameter in a more developed ecotaxonomy e.g. low, moderate, high population densities as defined in ecological literature. Although perceptions of density dependant patterns may change when such a parameter is brought into an ecotechnological arena.
- ◆ The use of different biotic indices especially those which utilise multivariate techniques and thus retain information. For example; TWINSPAN (Hill, 1979) has been used to classify the running waters of Great Britain on the basis of the microinvertebrate fauna. In west Wales it has been used as an indicator of organic pollution which has been adopted into a simple flow chart. After a kick sample is made on site the assessment procedure is simple enough to be used by non-biologists after a short period of training to enable rapid pinpointing of pollution sources with the minimum of resources. It is possible, that using the development of such flow charts, for other water bodies, it would be possible to derive from the parameters used an additional set of variables with which to develop the ecotaxonomy. This would be based not only on indicator species but on aquatic organisms in general and their relationships, direct or indirect with such established bioindicators and the way in which they contribute to their environment/water quality.

10.5.2 Ecotaxonomic Framework for Socio-Techno Innovation and Using 'natural' Systems Generally.

Although this research has used the example of wastewater- fed aquaculture and the organic loading of natural systems, the concepts developed are applicable to defining and using 'natural' systems generally.

The ecotechnological, ecological engineering principles in this research identified a need to map between different disciplines and sub-disciplines. This idea can also be applied generally for example when looking at 'natural' terrestrial systems.

Take for instance agricultural production. Agricultural systems rely, like aquatic ones, upon a medley of abiotic and biotic components as Pimentel et al., point out.

“Soil, water, air, energy and biological resources are essential for agricultural production. The complex ecological interaction among these resources must be understood so that they can be managed as an integrated system for a productive, sustainable agriculture” (Pimentel et al., 1988).

The ecological engineering of an agroecosystem is, as for aquatic systems, complex and requires some simplification by focusing primarily on commonly manipulated factors. These are soil nutrients (nitrogen, phosphorous, potassium, etc.), water, energy and pests.

“The goal is to conserve soil nutrients and water, while at the same time encouraging beneficial organisms and discouraging pests... Conserving soil and water resources reduces the inputs of commercial fertilizers and irrigation needed and thus decreases costs. Similarly, manipulations of the agroecosystems that encourage pest control and make the environment unfavourable for pests reduce the use of pesticides” (Pimentel et al., 1988).

A particular agroecosystem, ecological engineering scenario could thus require input from the following scientific disciplines/ sub-disciplines:

- ◆ Biochemistry
- ◆ Soil science
- ◆ Biology
- ◆ Ecology
- ◆ Hydrology
- ◆ Biotechnology (pest and pathology control)

The inclusion of biotechnology may seem to be at odds with the concept of ecological engineering but an understanding of the pathogens at a genetic/ cellular level and their adaptivity could be enhanced by a level of biotechnological knowledge. This does not mean that the system itself should be subject to bioengineering as opposed to ecological engineering as biotechnology cannot, by merit of its academic boundaries, operate at the macrobial self-organizing (ecological) level.

By combining some context driven, relevant attributes which are classified in the disciplines/ sub-discipline above, a land-based ecotaxonomy could be created to describe organisms in terms of, for example, either their pathogenic or beneficial characteristics when operating as group members of a soil system.

The ecotaxonomic research could be utilised by other applications in the International Ecotechnology Research Centre (IERC) which are being created to develop an understanding of emergent ecological organization in ‘natural’ systems involving innovation and technological change, and evolving economic models. All such investigations are subject to observing how innovation and change require diversity between the individual members comprising the group or organisation and the use of imperfect knowledge bases. An ecotaxonomic approach reveals such functional diversity and allows it to be relevantly classified according to the system of interest, and to investigate the divergent processes and values which result from a diversity of interacting types.

The ecotaxonomic approach uses key variables (relevant data) to develop a classification framework specific to the research issues and the development of models. Because the nested key variables are generally from different disciplines the ecotaxonomy can be used to create an interdisciplinary framework. This can include the use of components of classic classificatory systems but in a way which bridges the perceptual divide between disciplines and their languages (taxonomies).

This means such an ecotaxonomic approach can be utilised for any interdisciplinary research project which requires investigating the interaction between physical, chemical, biological and socioeconomic variables. Table 10. 1 below contains relevant examples:

Table 10.1 Research Projects which could Utilise an Ecotaxonomic Approach

NAME OF PROJECT	BRIEF DESCRIPTION OF PROJECT
Argolid Study	“A geographically-coupled linked physical, biological and socioeconomic model for land-use, to analyse and combat possible land degradation and desertification on the coastal plain around the city of Argos in Greece. It is part of the EU’s ‘Archaeomedes’ programme.” (IERC,1996)
Ermes	“An integrated methodology for projecting the impact of climate change and human activity on soil erosion and ecosystem degradation in the Mediterranean, using a climatological gradient and dynamical systems approach”
Rhone Valley Model	“A nonlinear coupled hierarchical model for the water quality of the river and neighbouring coastal waters, to explore the impacts of possible environmental policies and economic and demographic development”
The Tiger Project	“How to improve models of global climate change, taking into account the highly non-linear coupling of agriculture and climate, to model dynamically changing spatial patterns of vegetation cover and land use.”

(Information IERC, 1996)

Taking for instance the Argolid study, an ecotaxonomy could have been used to map data from the social enquiry side of the investigation i.e. data on farmer’s crop choices to local environmental data in a way which would enable species of organisms to be classified according to relevant parameters such as:

- ◆ Tolerance to salinity
- ◆ Tolerance to water loss and dry conditions
- ◆ In the case of plants; root depth
- ◆ Yield variation
- ◆ Remineralization potential
- ◆ Ecological interaction e.g. when one crop type has the potential to remineralize the soil for another
- ◆ Water trapping potential

If alternative types of species were found that fulfilled such relevant ecotaxonomic criteria than these could be recommended for trials during the adaptation of European agricultural policies and with reference to developing strategies of subsidisation.

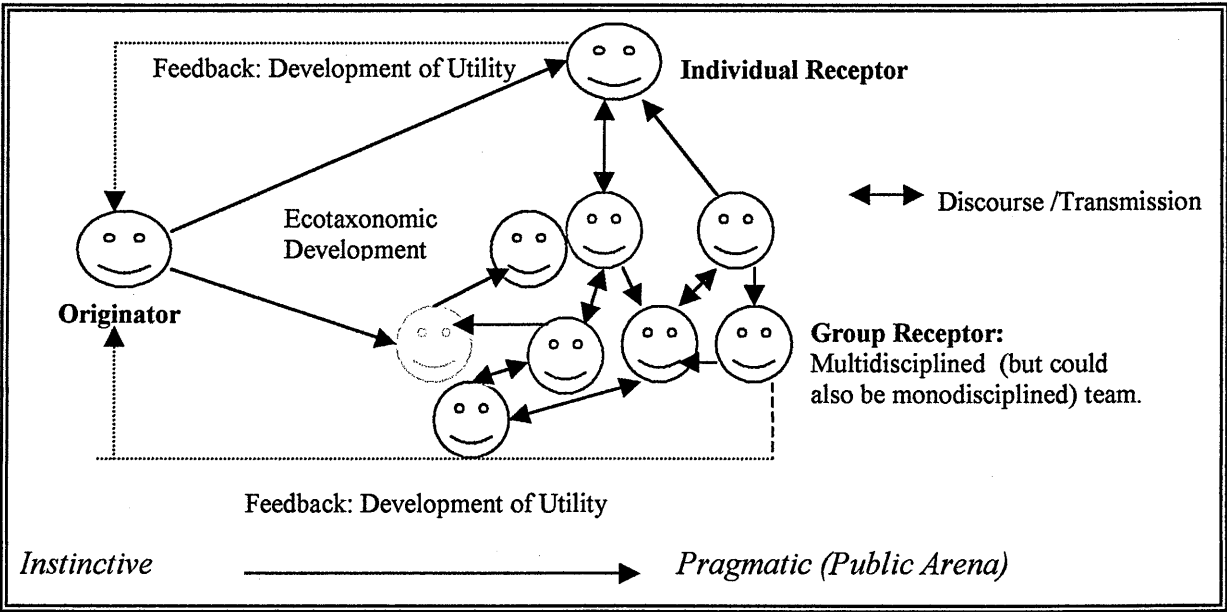
On a more general note the idea of such ‘inter’ taxonomies can be applied to virtually any situation which requires an interdisciplinary approach which has input from disciplines which are closely related enough to have shared characteristics classifying the attributes which comprise them.

10.5.3 The Ecotaxonomy: Mindsets & Multiple Mindsets

This thesis has described a singular cognitive journey but relates to ideas of using ecotaxonomic structures as interdisciplinary tools for both individual researchers and multi-disciplinary teams of researchers although the latter would necessitate a consensual agreement as to which criteria will define a particular ecotaxonomic framework.

Fig 10.4 Ecotaxonomy: A Cognitive Tool for Use by an Individual or by a Group

Transforming an intuitive process to an accessible cognitive tool for Interdisciplinary Approaches to Complex Research Problems.



The above diagram illustrates how the ecotaxonomic approach can be utilised in social and economic organizations as a tool which will

“facilitate knowledge transfer and translation” (Seaton, 1997, Browne, 2001).

The use of taxonomic development to define knowledge and its transfer is itself a rapidly advancing area of research;

Work by M^cLellan (2000) categorised engineering design knowledge, within multidisciplinary design projects, in order to select the most effective means of capturing and implementing this knowledge within an Intelligence Design Support System, the IDSS.

Knowledge, itself, was classified into five categories of action that knowledge could apply to information these are:

- ◆ Augmentation
- ◆ Generation
- ◆ Transformation
- ◆ Mapping
- ◆ Evaluation

At present there is an ongoing research project (Browne,2001) investigating whether it is possible to classify managerial types as knowledge transfer facilitators in organisations according to the type of management training received. In this way the research is mapping historical training data to real-time perceptions that managers have of themselves and the way they operate. The simple classification of managerial types being tested could be described as an ecotaxonomy which uses the functional classification of a manager as an individual and mapping function to develop theories of the processes of knowledge transfer in groups/organisations i.e. human ecology.

On a general note the idea of such ‘inter’ taxonomies can be applied to virtually any situation which requires an interdisciplinary approach which has input from disciplines, scientific or practical, which are closely related enough to have shared characteristics classifying the attributes which comprise them.

10.6 Ecotaxonomic Implications for Ecological Perspectives on Diversity, Stability and ‘natural’ Systems

In addition to classifying individuals as interactive group members and thus being representative of concepts such as hierarchy and emergence, the ecotaxonomy also highlights possible misconceptions about how humans perceive ‘natural’ bio-diversity.

When this ecotaxonomy was applied to biological data (Chapter 9) it obviously generated a different concept of the systems diversity. This has implications for perceiving the idea of resilience in ‘natural’ systems when a systems stability is related to its diversity.

The research can be used to a certain extent, to question whether the diversity-stability hypothesis (Section 4.3.1) is, in fact, simply a popular ecological myth which reflects a general eclectic human desire for maintaining bio-diversity at all costs. Even ecologists who understand, not only the integration of human and non-human components in a system, but also the shifting (evolutionary) nature of diversity fall into the ‘conserve all at all cost’ trap, as the following quote illustrates

“a social integration of human and non-human nature...interlocked in one humming community of co-operations and competitions... this interlocking requires each of us to extend his or her social instincts and sympathies to all the members of the biotic community” (Callicot, 1989).

The ideas of resilience, diversity and stability in systems was addressed in Section 4.3.1. During the late 1960's the diversity-Stability hypothesis (Section 4.3.1. iii) achieved in ecological circles the status of proposed truth, becoming in effect an ecological theory or paradigm. In the last ten years however, at least in its original form, the concept has virtually been refuted (Gagoff, 1985, Taylor,1986)

Without wishing to become too embroiled in hefty debates as to the value of the diversity – stability hypothesis in ecology it deserves at this point a brief mention. The diversity – stability hypothesis can be summed up as follows. Communities which are perceived as more diverse in terms of species number are thought of as more stable than those which comprise less species and some “balance of nature” is maintained by promoting diverse communities of species. The following ecological theorists are preservationists and as such argue that humans must exercise caution when changing ecosystems so as to protect biological diversity and thus maintain the dynamic stability or the balance of naturally functioning ecosystems.(MacArthur 1955, Elton 1958, Hutchinson 1959, Lewontin 1969, Wilson and Bossert 1971, Futuyma 1973, Innis 1974, Wu 1974, De Angelis 1975, Goodman 1975, Worster 1977, McIntosh 1985).

This is despite the fact that both mathematical and empirical reasoning has challenged the theory. Table 10.2 gives two classic examples which refute the Diversity-Stability hypothesis;

Table 10.2 Counter Examples Refuting the Diversity-Stability Hypothesis

Salt Marsh Systems	Rocky Intertidal Systems
Simple species composition but is stable in that the species composition does not change over time	Relatively diverse in nature but is highly unstable in that it may be perturbed by a single change in its species composition

It should be noted from this that the notion of stability is an unstable one being dependent on context and perception.

Despite this many ecologists continue to maintain that generally complex trophic systems and species diverse communities are more stable than less diverse ones by merit of enhancing the ecosystems flexibility to change and thus resilience. This may be so, but whether the functional complexity of a trophic system is directly related to species variety or that of some other taxon is unclear and can be investigated by experimenting, as in this research, with the concept of taxonomic manipulation.

By changing the identity of diversity in a system ideas of stability and equilibrium are seen for what they really are i.e. static perceptual tools with which to define an ever

changing environment. What is more, such ideas may hinder an appreciation of the self-designing capacity of natural systems.

“Ecotechnology involves an acceptance of the concept of the self-designing capability of ecosystems and nature. We may even go as far as to say that the concept of a polluted ecosystem is an anthropogenic view, one that may not recognize the beauty of natural systems shifting, substituting species, reorganizing food chains, adapting as individual species, and ultimately designing a system that is ideally suited to the environment that is superimposed on it “ (Mitsch and Jørgensen, 1989)

The ecotaxonomy, by taking into account the feedback loop from non-human nature to human nature, gives a different appreciation of functional diversity and thus any stability described by it is, not merely a reflection of species variety, but also of the context driven functionality associated with it or vice versa. Also the term stability is actually a misleading one and should not be equated with optimality which might actually require a certain level of instability.

The specific ecological engineering ecotaxonomy developed in this research could contribute to developing ideas on biodiversity in ‘natural’ systems and the concept of stability and the ‘balance of nature’ and whether these are actually useful concepts. Currently (ecological) debates on stability, equilibrium and non-equilibrium hypotheses and sustainability do not tend to dispute the way in which the diverse elements (organisms) are classified. There appears to be little research which investigates the effect of changing the way in which diversity and those related topics of stability etc. are perceived via shifting taxonomic agendas. Some ecological researchers do classify using guilds etc but still the social basis of ‘nature’ and the effects and requirement of humans are not usually taken on board within such classification.

Ambitions to link the social and natural sciences by taking a systems approach are to an extent thwarted by the idea that it is the close interaction of natural and social systems as a functional whole which needs to be investigated. This still presents the researcher with a perceptual divide between human and ‘Natural’ systems when in actuality the interaction is such to produce a ‘natural’ system where human physical and social behaviour is as natural as the environment in which it operates. The consequence of such a perception is the continual collection of excess data

“—classically in the form of lists and classifications—that remain poorly situated in the complexities of environmental and social processes.” (Scoones, 1999)

The Research Design (Chapter 5) and the Ecotaxonomic development addresses the need to stop simply listing organisms as components of biodiversity without reference to physical processes which impinge on the human component.

The Ecotaxonomy developed in this research enabled the biodiversity of a ‘natural’ system as a large number of Linnaean types/species to be reduced to fewer numbers of functional types reflective of a biodiversity related to specific water quality change.

On a global level biodiversity measures are related to ideas of conservation and preventing the extinction of those organisms which humans perceive as worthwhile for aesthetic, farming or other reasons. This research accepts that notions of biodiversity and retention of types should be dependent on situation rather than simply universal eclecticism, human activity and species extinction is by no means a (clear) linear relationship anymore than is human activity and conservation of biodiversity.

This research has developed from a scientific perspective situated within, appropriately enough, the 'natural sciences' i.e. biological sciences. It has attempted, by the use of an ecological engineering model to take a more social approach to biological classification. Other researchers from the social sciences also harbour a similar objective

"a major task for the social sciences will be to decipher the social implications of what has always been the case, namely, a nature elaborately entangled and fundamentally bound up with social practices and their characteristic modes of cultural representation" (McNaghten & Urry, 1998)

Harding, 1991 wrote about the renegotiation of the boundaries of the social and natural sciences whilst more radically Latour, 1993 proposed the creation of a "symmetrical anthropology" where nature-culture divisions disappear altogether.

The negotiation of expertise is also a fundamental utility of this research where the scientific description is no longer couched in taxonomic jargon and classificatory terms can be utilised by 'lay' / the non-scientific fraternity. This relates to the general epistemological issue of modes of discourse when complex problems are being addressed. This research has revealed that the utility of a discipline is often reflected in its taxonomic systems, in this way taxonomies are often language specific to a discipline. Interdisciplinarity necessitates becoming multi-lingual or failing that, developing a new unifying language or taxonomic framework.

The ecotaxonomy as an example of 'praxis' also highlights the need for investigation of

"science in action" (Latour, 1987)

which includes looking not only at the general scientific practices of scientists in their laboratories and the various 'types of' taxonomists collecting and classifying data in the field, but also the role of technologists, field/site managers, project assistants others involved in process and implementation and their interaction.

The ecotaxonomic approach also enables the engineers of systems to become part of the design trajectory of the system and its processes. It does this by providing a framework which, recognises the potential of harnessing the organisms as the selforganizing design fractions or the intrinsic ecological engineers of the system. It does this in a way which, is context driven according to cultural necessity and demand but not inflexible to change. A single organism can be ecotaxonomically described

using infinite parameters to define whichever of its roles is of principal interest to a specific research study.

An ecotaxonomic system releases biological taxonomy from the confines of the Natural Historical perception and the electism intrinsic to simple biodiversity study so that it can become a useful tool for mapping between the science and social sciences and thus the nature-culture divide.

The ecotaxonomy is pertinent to

“the increasing recognition of the need to go beyond the restrictive nature-culture divide-which- pushes us to challenge other unhelpful dichotomizations and so encourages a more integrative style of enquiry... ..for it is the interaction between these two perspectives-socially constructed perceptions and representations and real processes of biophysical change and ecological dynamics-that is key to policy and practice” (Scoones, 1999)

The more integrative style of enquiry mentioned above by Scoones is also referred to as a range of methodological approaches namely hybridity, innovative eclecticism (selective biodiversity) and not least, interdisciplinarity.

Taxonomy in general links to the idea of ‘system’ because it can act simply as a perceptual tool with which humans can view the world in ‘order’ to make some sort of sense out of chaos (excepting the sense that certain fundamental scientists already make out of chaotic activity in a system).

10.7 Implications for Mapping Social and Technological Systems

10.7.1 Objective Biological Classification

The ecotaxonomy represents a shift in perception with respect to ‘Natural’ systems moving away from a phylogenetic* representation of flora and fauna and paradoxically the ‘natural’ evolutionary processes and moving towards a context driven description of a socially directed biophysical or ‘natural’ system. It is by no means a comprehensive attempt to reclassify organisms as ecological engineers of waste treatment. It simply represents a move toward incorporating sociological aspects of change, as well as evolutionary change, into the classification of living organisms. Table 10.3, on the following page, compares traditional natural biological taxonomy and the proposed objective biological ecotaxonomy.

Table 10.3 “Natural” Biological Classification and “Objective” Biological Classsification

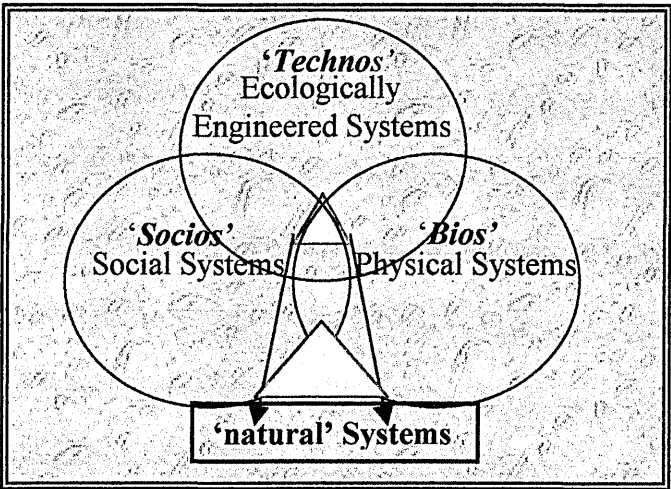
Traditional “Natural” Biological Taxonomy	Objective Issue Driven, Biological Ecotaxonomy
By incorporating traditional Linnaean classification with developing molecular biological techniques the classification of biological variety both extinct and extant enables a ‘real’ world picture, in natural historical terms, to be generated by the creation of a ‘natural’ taxonomy. In which Homo sapiens are included as a species but not as ‘the’ taxonomist.	A redefinition of the biological types classified by the ‘natural’ taxonomic system to define useful extant interrelationships and self-organizing processes which create the system of interest via emergence. Such classification systems are only ‘natural’ in anthropocentric terms in that they incorporate the element of purposefulness or human control. in addition to the effects of a purposive biological system.

10.7.2 How Interdisciplinary?

Although the substantive research of the previous chapters appears to be lodged firmly within a biological science framework the idea of mapping the taxonomies of different disciplines or sub-disciplines is relevant to the wider ideal of interdisciplinary research and of mapping between the sociological and technological aspects of a system. In this thesis an attempt is being made to map between the socially needed attributes (not only in physical terms of human pollution but also in epistemological terms i.e. the way humans learn about and describe systems) and technology in terms of ‘applied knowledge.’ This has been done in the context of ecological engineering where the definition of ‘natural’, ‘ecotechnology’ and ‘sustainable’ system require some scrutiny.

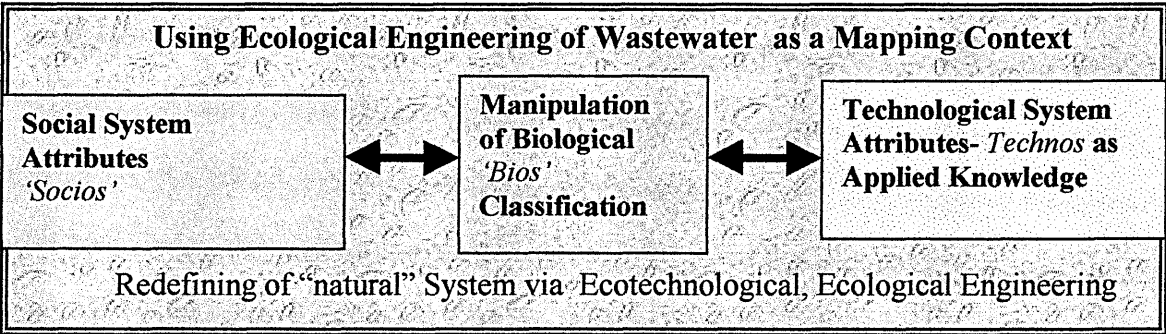
The concept of natural is seen to arise from the interaction of the relevant physical, technological and social systems (Fig. 10.5). In this way nature incorporates all the relevant aspects of humanity in addition to traditional biological and ecological concepts.

Fig. 10.5 ‘natural’ Systems in this Thesis



To a certain extent the biology (*bios*) of the system has, therefore, been used to map social system attributes (*socios*) to ‘soft’ technological system attributes (*technos*) in the form of ‘applied knowledge’

Fig. 10.6 Mapping Attributes Beyond the Biological Sciences



10.9 Final ‘natural’ Perceptions

The redefining of organisms as ecological engineers attempts to show that humans do not have total monopoly over environmental construct although it is possible for *Homo Sapiens* to be the engineers of ecological engineers. The study also attempts to naturalize the effect humans have on their environment, admittedly in doing this it does, to a degree, denaturalize other organisms and take a rather mechanistic (engineering) stance to simplifying their (eco) functionality.

Traditionally ‘Natural’ systems are complex ones but ‘natural’ systems in the ecotechnological sense are even more complex in that they need to include the extra emergent levels (phenomena) which arise from the inclusion of *Homo sapiens* in ecological systems.

The epistemological devices such as the taxonomic systems involved in describing and learning about natural processes, although useful, should not be confused with the actual physical processes of change in such complex systems. In the case of conceptualising natural systems as emergent phenomena arising from the interactions of their ‘natural’ components, biological taxonomy has a role in negotiating the man/nature divide whether perceptual or otherwise.

However when dealing with concepts such as interdisciplinarity, hierarchy and emergence in scientific circles, the medium should not be confused with the message.

“It is a universal property of language (and hence all description) that the structure of symbol vehicles or signs (i.e. the letters of the alphabet, nucleotides, words, codons, etc.) are related to their referent or their effect by arbitrary rules. These rules are not derived from, or reducible to the laws of nature. They are perhaps best described as frozen accidents-accidents because their antecedent events are unobservable” (Pattee, 1978).

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Glossary

Abiotic – Non-living (non-animate) devoid of life.

Activated Sludge – The sludge removed from an activated sludge treatment process. It comprises bacteria and protozoa, which can live and multiply on sewage. Due to these organism's rapid multiplication they require continuous removal. Part of the activated sludge acts as a 'seed' and is returned to the raw sewage whilst the rest is sent for disposal (land, sea or incineration).

Aerobic – Of an environment where oxygen is present or describing a process which requires oxygen.

Aerobe – Organism which requires the presence oxygen to survive.

Anadromous – Refers to the migratory behaviour of fish species which spend most of their life in the sea, but then migrate to fresh water to spawn, salmon are a classic example.

Anaerobic- Of an environment where oxygen is absent or a process which occurs only in the absence of oxygen.

Anaerobe – An organism which only exists in the absence of oxygen.

Alga(e) – The common (non-taxonomic) name for a relatively simple type of 'eukaryotic' plant which is never differentiated into root, stem and leaves. They can be found in most habitats but the majority occurs in freshwater or marine systems.

Algal Bloom - A sudden growth of algae in an aquatic system which can occur naturally in spring or early summer when 'primary production' exceeds consumption by aquatic 'herbivores'. Blooms may also be induced by nutrient enrichment of waters due to 'pollution' and are a characteristic symptom of 'eutrophication'.

Animal manure water – Wastewater (effluent) draining from farmland.

Autotroph - An organism which uses carbon dioxide as its main or sole source of carbon e.g. plants which photosynthesis using carbon dioxide.

Autrophism/Autorophic – A type of nutrition in which organisms synthesize the organic materials they require for living, growth and development from inorganic sources. Chief sources of carbon and nitrogen are carbon dioxide and nitrates, respectively. All green plants are autotrophic and use light as a source of energy synthesis i.e. they are photoautotrophic (see photosynthesis) Some bacteria are also photoautotrophic, others are chemoautotrophic using energy derived from chemical processes.

Bacteria (I) – A diverse group of ubiquitous ‘micro-organisms’, all of which consist of only a single cell that, lacks a distinct nuclear membrane and has a cell wall of unique composition..

Basal Species – have predators but no prey (Briand and Cohen 1984).

Benthic – Describes organisms which live on the bottom of an aquatic system.

Benthos – The collection of organisms attached to, or resting on, the bottom sediments (epifauna) and those which burrow or bore into sediments (infauna) of an aquatic system.

Biochemical Oxygen Demand (BOD) – A standard water treatment test for the presence of organic pollutants. The test depends on the activities of bacteria and other microorganisms, which in the presence of oxygen feed upon organic matter. The result of the test indicates the amount of dissolved oxygen in grams per cubic metre used up by the sample when incubated in darkness at 20°C and in the UK for 5 days, BOD₅.

Biocoenosis (Biocoenoses) - The living part of a ‘biogeocoenosis’ comprising the ‘phytocoenosis’, the ‘zoocoenosis’ and the microbiocoenosis. It s equivalent of the ‘biotic’ component or the ‘biome’ in an ‘ecosystem’.

Biodiversity – A portmanteau termed which gained popularity in the late 1980’s it can be used to describe all manner of biological diversity especially including ‘species richness’, ecosystem complexity and genetic variation.

Biogeocoenosis – A term equivalent to ‘ecosystem’ which is used in Soviet and Central European literature. It comprises the ‘biocoenosis’ together with its habitat, ‘ecotope’.

Bioindicators/Biotic index – Living organisms (biota) used to detect environmental (abiotic) change.

Biomagnify-The phenomena by which contaminants are accumulated in organism’s in progressively higher amounts along the food chain i.e. carnivores will contain much greater concentrations than the herbivore on which they prey.

Biology – The study of living organisms.

Biome – A biological subdivision that reflects the ‘ecological’ and ‘physiognomic’ character of the vegetation. Biomes are the largest geographical ‘biotic’ ‘communities’ that it is convenient to recognise and broadly correspond to climatic regions.

Biotic – Applied to the living component of the ‘biosphere’ or of an ‘ecosystem’ as distinct from the ‘abiotic’ physical and chemical components.

Chemotroph/Chemotrophic – An organism which obtains its energy from chemical reactions.

Cladistics – A method of biological classification in which animals and plants are placed into taxonomic groups called 'clades' when they share characteristics (homologies) that are thought to indicate a common ancestry. It is based on the assumption that two 'species' are formed suddenly by splitting from a common ancestor, and not by gradual evolutionary change and is in this way somewhat opposed to neo-Darwinist thinking.

Climax Community(ies)- The final stage of plant 'succession' in which vegetation reaches a state of equilibrium with the environment and community is self-perpetuating.

Converter – A 'Stella II' icon (circle) which serves a utilitarian role in the software converting inputs into outputs. It does this by holding values for constants; defining external inputs to the model, calculating algebraic relationships and serves as a repository for graphical functions.

Copepod – A subclass of aquatic crustaceans which are important members of plankton.

Cyprinids – Refers to fish of the family cyprinidae which are by far the largest family of fish (fresh water) and include carps and minnows.

Cytoplasm(ic) - Referring to the jelly-like material surrounding the nucleus of a cell it can be differentiated into an outer ectoplasm and an inner endoplasm, the latter contains the majority of cell's structures (organelles).

Cyanobacteria – Also known as blue-green algae from when they were formerly regarded as 'algae' but now are thought to be 'bacterial'. They are 'autotrophic' and 'photosynthesise' in the presence of light and air with the concomitant production of oxygen. Their taxonomy is confused because most of the 'phycological' genera and species (defined when they were regarded as algae) are now known to be based on unreliable characteristics i.e. ones, which depend on conditions of growth and they have be redefined or abandoned depending on bacteriological criteria.

Denitrification- The return of fixed nitrogen, generally nitrates and ammonium salts, to the atmosphere generally as N_2 and N_2O .

Detritivore – A heterotrophic animal which feeds on dead material (detritus).

Detritus – Litter formed from the fragments of dead material e.g. leaf litter, dung and corpses. In aquatic habitats, detritus provides habitats equivalent to those, which occur in soil humus.

Dissolved Oxygen Level (DO) – The concentration of oxygen held in solution in water. Usually measured in mg/l.

Diurnal Rhythm – Daily patterns; denoting an event or patterns of them, which occur once every 24 hours.

Diversity – Most simply the ‘species richness’ of a ‘community’ or an area, although it provides more useful community characteristics when it is combined with an assessment of the relative abundance of species present. Diversity in ‘ecosystems’ has been traditionally associated with stability and ‘climax’ communities.

Ecology/Ecological – The scientific study of the interrelationships among organisms and between organisms and between them and all aspects, living (biotic) and non-living (abiotic) of their environment. Ernst Heinrich (Haeckel) is credited with having coined the term in 1866.

Ecosystem - Term first used by Tansley in 1935 to describe a discrete unit which consist of living (biotic*) and non-living (abiotic*) parts interacting to form a stable system. Fundamental concepts include the flow of energy via food chains* and food webs* and the cycling of nutrients biogeochemically. Such principles can be applied at all scales. In Soviet and Central Europe the term biogeocoenosis is used instead.

Ecotope – The habitat component of a biogeocoenosis*.

Entomostraca-General term for non-malacostracan (class containing nearly 75% of all crustacea) crustaceans.

Epiphytic – Used to describe a plant which uses another plant for it’s physical support but does not draw nourishment from it.

Eukaryote – An organism whose cells contain a distinct nucleus enveloped by a double membrane and also double membraned mitochondria.

Eutrophication – The process of nutrient enrichment usually by nitrates and phosphates in aquatic systems such that, the productivity of the system ceases to be limited by the availability of nutrients. It occurs naturally over geological time, but may be accelerated by human activities such as sewage disposal or land drainage this can be termed ‘cultural eutrophication’. The rapid increase in nutrient levels stimulates algae blooms*. On death of these algae bacterial decomposition of the excess algae may seriously deplete the oxygen levels in the system.

Faecal Coliforms – Coliforms are a group of bacteria whose absence from drinking water is regarded as a guarantee of freedom from pathogenic bacteria. Faecal coliforms occur in untreated faeces.

Fingerlings – Descriptive term for juvenile fish.

Food Chains – are direction paths of trophic energy or, equivalently, sequences of links that start with producers or fine organic matter, and end with consumer organisms.

Gene – A unit of heredity composed of DNA .

Genotype – The genetic composition of an organism.

Gram's Stain – A staining method used to differentiate between types of bacteria.

Guild – A group of species all members of which exploit similar resources in a similar fashion.

Herbivores- A heterotroph which obtains its energy by feeding on primary producers normally green plants.

Heterotroph/Heterotrophic - An organism that is unable to manufacture its own food from simple chemical compounds and therefore has to consume other organisms, living or dead as its main or sole source of carbon.

Intermediate Species – have both prey and predators (Briand and Cohen 1984).

K-select species – Species that use a k-select strategy to survival i.e. maintaining low birth rates and high survival rates of offspring.

Limnology/Limnological – The study of freshwater ecosystem especially lakes.

Macrophyte – Aquatic plants excluding algae. They occur as floating, submersed and immersed types.

Micrometazoans – Microbial multicellular organisms. These are one of the three kingdoms of multicellular organisms the other two being fungi and metaphyta (plants).

Microorganism – Any organism that cannot be resolved with the naked eye i.e. require microscopy to view them.

Microtubules – Minute protein tubules/filaments which occur in living cells and contribute to the maintenance of cellular structure.

Mineralization – The process of breaking down organic waste.

Nauplii – The first free-swimming larvae of planktonic larvae of marine and freshwater crustaceans.

Nitrification – Chemical process where nitrogen mostly in the form of ammonia in waste (excretory) is oxidized first to nitrites and then to nitrates.

Omnivores - A heterotroph which feeds on both plants and animals.

Pathogens – Any micro-organism which causes disease.

Pelagic – Organisms, which inhabit open water.

Phenotype – The observable characteristics of an organism as determined by its genes and environmental interactions.

Photosynthesis – The process by which green plants synthesise organic compounds from carbon dioxide and water in the presence of sunlight..

Phototrophic/Phototroph – An organism which obtains it's energy from sunlight, in most case via the process of photosynthesis.

Phycological- Related to the study of algae (phycology)..

Phylogenetic (phylogenic) – The classification of organisms on the basis of the degree of evolutionary relatedness.

Phylogeny – Evolutionary relationships within and between taxonomic levels.

Physiognomic – Related to the form and structure of 'natural' communities.

Phytocoenosis – The primary producers which form the productive part of the biocoenosis in a biocoenosis.

Phytoplankton- The plant plankton component of aquatic ecosystems.

Planaria-An order of free-living worms i.e. non-parasitic.

Pollution – The introduction into the environment of substances or effects that are potentially harmful or interfere with human's use of their environment or with species or habitats.

Polymorphic Trait – A trait (genetic) occurring in multiple forms in a population.

Piscivorous – Fish eating species.

Primary Production – The rate, at which biomass, in the form of organic substances, some of which is, used a food material is generated. Most primary productivity is produced by photosynthetic and chemosynthetic autotrophs (mostly green plants).

Primary Treatment - This usually involves some slowing down of the sewage flow by putting the effluent (treatment works influent) into a chamber so that the suspended solids (mainly organic material) settle to the bottom of the hold through the force of gravity, or float to the surface by buoyancy (e.g. Fatty compounds). This is principally a physical process. Since the material, which settles out, tends to be organic, the total BOD of the sewage, which continues through the system, is reduced.

Prokaryote – An organism usually unicellular in which cells lack a true nucleus i.e. the genetic material is not enclosed in a nuclear membrane.

Predators – Typically an animal, which catches, kills and eats its prey, but predation also, includes insectivorous plants and grazing interactions.

Reed Beds – Beds of soil or a gravel media in a sealed pit containing reeds (usually the species *Phragmites australis*) for the treatment of effluent. BOD removal is in the range of 80-90%.

Rotifer – (wheel animalcules). A class (or phylum in some classification systems) of small (largest individuals reach about 3mm) generally freshwater organisms.

R-Select species – Species which use the opposite survival strategy to k-selection i.e. produce lots of offspring to offset a high mortality rate, they are opportunistic.

Saprobies- Organisms of decomposition and decay.

Saprobic System- A classification of freshwater organisms according to their tolerance of organic pollution. Created in 1902 by Kolkwitz and Marsson.

Saprobien System – An alternative term for the Saprobic System.

Saprobian System- A derivation of the original Saprobic system and includes further levels of saprobity (decay).

Secondary Treatment – This process removes most of the BOD remaining in effluent after the primary process of settlement etc. It is also known as biological treatment since it depends on micro-organisms breaking down the organic material in the sewage. This biological treatment, simply, requires the creation of environment where aerobic degradation can occur at an accelerated rate. It thus requires a habitat for micro-organisms, oxygen for aerobic treatment and a way of removing dead micro-organisms, such as a settlement tank.

Settleable Solids (SS) – The amount of matter (organic and inert) suspended in sewage that will at some point settle.

Sewage Sludge – An accumulation of settleable solids. The quantity and nature of the sludge generated relate to the character of the raw wastewater and processing units employed (or not).

Suspended Solids (SS) – In stream-pollution-control work all suspended solids are considered to be settleable solids as time is not a limiting factor. Deposition is expected to occur through biological and chemical flocculation. The measurement of suspended solids is considered fully as significant as BOD.

Sustainability- There are many contemporary debates regarding this term, traditionally sustainable development has been most simply defined as 'development

which meets the needs of the present generation without compromising the ability of future generations to meet their own needs. It has been represented, as the overlap of social needs, economic needs and environmental capacity.

‘Socially directed biophysical technologies’ – Any technology which harnesses ‘natural’ biophysical processes as opposed to simply using purely man-made ones.

Speciation- The development of one or more species from an existing species.

Species - A category used in the classification of organisms that consists of a group of similar individuals that can usually breed among themselves and produce fertile offspring.

Species Richness – The diversity of species in a community measured as the number of species compared with the number of individuals (abundance) in the community. Can also be termed species diversity.

‘Stella II’ – A software, conceptual modelling package. It can be used to provide a multi-level hierarchical environment for constructing and interacting with models. This research simply uses the package as an illustrative device rather than to compile a running model.

Stock – A ‘Stella II’ icon (square) which represents accumulations/reservoirs of whatever model parameter flows in and out of them. A reservoir passively accumulates its inflows, minus its outflows. Any units which flow into a Reservoir will lose their individual identity i.e. all units are mixed into an undifferentiated mass as they accumulate.

Taxon- the finest level of taxonomic definition and can be an arbitrary group of organisms e.g. fine organic matter, a life history stage of related organisms, a species, a genus, or a family.

Tertiary Treatment –Also called advanced wastewater treatment. This can involve physical, biological, and/or chemical processes. It refers to the continued removal of BOD and SS after primary and secondary treatment, the removal of nutrients, nitrogen and phosphates and removal of pathogenic organisms.

Treatment Lagoons- Another term for Stabilization Ponds, oxidation ponds, settlement ponds or solar ponds which are generally employed for secondary treatment in rural areas,

Top Species – have prey but no predators. (Briand and Cohen 1984),

Trickle Filter – A fixed-growth biological treatment system with microbial growths attached to the surface of some supporting media (which can be synthetic). Where wastewater is sprayed over a bed of crushed rocks, the unit is commonly referred to as a trickle filter.

Trophic Species – refer to clusters containing all taxa with the exact same set of predators and prey (Briand and Cohen 1984) taxa, clusters, and trophic species specify aggregation levels of the more general term, **species**.

Trophic Concept – Confusingly the term trophic is also used to define the productivity (rate of organic matter supply) of lake ecosystems with oligotrophic systems being the least productive and eutrophic the most productive.

Zoobenthos – Animal component (as opposed to plant component) of the bottom dwelling community which inhabit the benthos.

Zoocoenosis – Animal (consumer) component of the biocoenosis.

Zooplankton – Animal component of plankton.

Appendices

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Appendix Table 1

Classification of Freshwater Organisms Using the Linnaean Taxonomic System

Section of database showing common freshwater organisms and including those traditionally considered important to wastewater management & Ecological Engineering.

V.A.T.T – Varies according to text, to such a degree that it is difficult to classify.

Common Name	kingdom	phyla/division	class	order	family	genus	species
Water Hyacinth	Plantae	Magnoliophyta Spermatophyta	Liliopsida	Typhales	Typhaceae	Typha	latifolia
Common Reed	Plantae	Magnoliophyta Spermatophyta	Liliopsida	Cyperales	Cypefaceae Juncaceae	Scirpus	lacustris
Common Noddy	Plantae	Magnoliophyta Spermatophyta	Liliopsida	Cyperales	Poaceac	Phragmites	Australis
Common Duckweed	Plantae	Magnoliophyta Spermatophyta	Liliopsida	Arales	Lemnaceae	Lemna	minor
Blue-green Algae	Monera	Cyanophycota Cyanophyta	Cyanophyceae	Nostocales	Nostocaceae	Anabaena	flos-aquae
Planarian	Animalia	Aschelminthes Rotifera	Monogononta	Ploima	Synchaetidae	Polyarthra	vulgaris
Planarian	Animalia	Aschelminthes Rotifera	Monogononta	Flosculariaceae	Filiniidae	Filinia	terminalis
Planarian	Animalia	Aschelminthes Rotifera	Monogononta	Ploima	Brachionidae	Keratella	quadrata
Planarian	Animalia	Aschelminthes Rotifera	Monogononta	Ploima	Brachionidae	Keratella	cochlearis
Planarian	Animalia	Aschelminthes Rotifera	Monogononta	Flosculariaceae	Hexarthridae	Hexarthra	bulgarica
Planarian	Animalia	Aschelminthes	Rotifer	V.A.T.T	V.A.T.T	Euchlanis	Spp.
Fleas	Animalia	Arthropoda Crustacea	Branchiopoda	Diplostraca Cladocera	Daphnidae	Daphnia	pulex

lar)				Eucladocera			
Fleas	Animalia	Arthropoda Crustacea	Branchiopoda	Diplostraca Cladocera Eucladocera	Daphnidae	Daphnia	galeata mendotae
lar)							
Fleas	Animalia	Arthropoda Crustacea	Branchiopoda	Diplostraca Cladocera Eucladocera	Daphnidae	Daphnia	longispina
lar)							
Fleas	Animalia	Arthropoda Crustacea	Branchiopoda	Diplostraca Cladocera Eucladocera	Daphnidae	Daphnia	retrocurva
lar)							
Fleas	Animalia	Arthropoda Crustacea	Branchiopoda	Diplostraca Cladocera Eucladocera	Daphnidae	Daphnia	schoedleri
lar)							
Fleas	Animalia	Arthropoda Crustacea	Branchiopoda	Diplostraca Cladocera Eucladocera	Bosminidae	Bosmina	longirostris
lar)							
Fleas	Animalia	Arthropoda Crustacea	Branchiopoda	Diplostraca Cladocera Eucladocera		Polyphemis	pediculus
lar)							
Fleas	Animalia	Arthropoda Crustacea	Branchiopoda	Diplostraca Cladocera Eucladocera	Holopedidae	Holopedium	gibberum
lar)							
Fleas	Animalia	Arthropoda Crustacea	Branchiopoda	Diplostraca Cladocera Eucladocera	Leptodoridae	Leptodora	kindtii
lar)							
ods ass	Animalia	Arthropoda Crustacea	Copepoda	Calanoida	Centropagidae	Limnocalanus	macrurus
ods lass	Animalia	Arthropoda Crustacea.	Copepoda	Calanoida	Diaptomidae	Diaptomus	shoshone
ods lass	Animalia	Arthropoda Crustacea	Copepoda	Cyclopoida	Cyclopoidae	Cyclops	biscuspidatu
hiopod lass	Animalia	Arthropoda Crustacea	Branchiopoda	Diplostraca	V.A.T.T	Mixodiaptomus	laciniatus
h	Plantae	Magnoliophyta Spermatophyta	Liliopsida Commelinidae	Cyperales	Cyperaceae	Scirpus	subterminali
h	Plantae	Magnoliophyta Spermatophyta	Liliopsida Commelinidae	Cyperales	Cyperaceae	Scirpus	acutus
sh.	Plantae	Magnoliophyta Spermatophyta	Liliopsida Commelinidae	Cyperales	Cyperaceae	Scirpus	acutus
Trout	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Protacanthopteryg ii Salmoniformes	Salmonidae	Salmo	truitta
ow d	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Protacanthopteryg ii Salmoniformes	Salmonidae	Oncorhynchus (Salmo) (Salmo)	mykiss (gairdnerii) (mykiss)
ern	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Protacanthopteryg ii Esociformes	Esocidae	Esox	lucius

n	Animalia	Chordata	Osteichthyes Actinopterygii Neopterygii Teleostei	Ostariophysi Cypriniformes	Cyprinidae	Carassius (Carassius) (Cyprinus)	carassius (vulgaris) (carassius)
sh	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Ostariophysi Cypriniformes	Cyprinidae	Carassius (Cyprinus)	auratus (auratus)
ling	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Ostariophysi Cypriniformes	Cyprinidae	Rhodeus	sericeus
Roach	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Ostariophysi Cypriniformes	Cyprinidae	Scardinus (Rutilus)	Erythrophthalmus
	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Ostariophysi Cypriniformes	Cyprinidae	Abramis (Cyprinus)	brama
	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Ostariophysi Cypriniformes	Cyprinidae	Blicca	bjoerkna
	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Ostariophysi Cypriniformes	Cyprinidae	Alburnus	alburnus
	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Ostariophysi Cypriniformes	Cyprinidae	Leuciscus	cephalus
	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Ostariophysi Cypriniformes	Cyprinidae	Alburnoides	bipunctatus
	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Acanthopterygii Perciformes Stromateoidei	Centrolophidae	Hyperoglyphe	porosa
w	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Ostariophysi Cypriniformes	Cyprinidae	Phoxinus (Cyprinus)	phoxinus
l	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Ostariophysi Cypriniformes	Cyprinidae	Barbus	barbus
	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Ostariophysi Cypriniformes	Cyprinidae	Tinca	tinca
	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Ostariophysi Cypriniformes	Cobitidae	Cobitis	taenia

erfish	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Ostariophysi Cypriniformes	Cobitidae	Misgurnus	fossilis
Loach	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Ostariophysi Cypriniformes	Cobitidae	Nemacheilus	barbatulus
fish	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Ostariophysi Siluriformes	Siluridae (freshwater catfishes)	Silurus	glanis
melts	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Acanthopterygii Atheriniformes Atherinoidei	Athernidae	Atherina	boyeri
ed eback n eback	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Acanthopterygii Gasterosteiformes Gasterosteoidei	Gasterosteidae	Gasterosteus	Aculeatus (niger) etc,
ined e	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Acanthopterygii Gasterosteiformes Gasterosteoidei	Gasterosteidae	Pungitus	pungitus
ad ater in	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Acanthopterygii Scorpaeniformes Cottoidei	Cottidae (Bullheads)	Cottus	gobio
kinsee	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Acanthopterygii Perciformes Percoidei	Centrarchidae (bass)	Lepomis (perca)	gibbosus (gibbosa) etc,
- ed	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Acanthopterygii Perciformes Percoidei	Centrarchidae	Micropterus	salmoides
Perch	Animalia	Chordata Vertebrata	Osteichthyes Actinopterygii Neopterygii Teleostei	Acanthopterygii Perciformes Percoidei	Percidae (perches)	Perca	fluviatilis
lates	Animallia	Cilioophora	Ciliata Rhabdophorina (Mastigophora	Hymenostomatida Peniculina	Parameciidae	Paramaecium	caudatum
bas	Animalia	Protozoa Sarcodina	Rhizopoda Lobosa	Amoebida	Amoebidae	Amoeba	Spp.
s	Animalia	Ciliophora	Ciliata Peritricha	Peritrichida Sessilina	Vorticellidae	Voticella	convallaria
ids	Animalia	Cnidaria	Hydrozoa	Hydroida Hydrida	Hydridae	Hydra	Spp.
rms	Animalia	Platyhelminthes	Turbellaria Archoophora	Tricladida	Dendrocoelidae	Dendrocoelum	Spp.
nted	Animalia	Annelida	Oligochaeta	Haplotaxida Tubificina	Enchytraeidae	Lumbricillus	Spp.
es	Animalia	Annelida	Oligochaeta Hirudinea	Gnathobdellida	Hirudinidae	Haemopis	sanguisuga
Mites	Animalia	Arthropoda	Arachnida	Hydracarina		Hydrodroma	despiciens

Snail	Animalia	Mollusca	Gastropoda Euthyneura	Basommatophora	Lymnaeidae	Lymnaea	stagnalis
tail flies	Animalia	Arthropoda Hexapoda	Insecta	Collembola	V.A.T.T	Collembola	Spp.
rog	Animalia	Chordata Vertebrata	Amphibia Apsidospondyli	Salientia Anura	Ranidae	Rana	Spp.
ean	Animalia	Chordata Vertebrata	Amphibia Apsidospondyli	Salientia Anura	Buфонidae	Bufo	bufo
	Animalia	Chordata	Amphibia			Triturus	vulgaris
ion	Animalia	Arthropoda Hexapoda	Insecta Pterygota	Heteroptera	Nepidae	Nepa	cinerea
en	Animalia	Arthropoda Hexapoda	Insecta Pterygota	Heteroptera	Notonectidae	Notonecta	Spp.
Stick	Animalia	Arthropoda Hexapoda	Insecta Pterygota	Heteroptera	Nepidae	Ranatra (Nepa)	linearis
ian ond	Plantae	Magnoliophyta	Liliopsida Alismatidae	Hydrocharitales	Hydrocharitaceae	Elodea	Canadensis (linearis) etc.
Fly	Animalia	Arthropoda Hexapoda	Insecta Pterygota	Neoptera Diptera Nematocerca Psychodomorpha	Psychodidae Psychodinae	Psychoda	Alternata (schizura)etc
Fly	Animalia	Arthropoda	Insecta	Diptera	Plecoptera	Perla	bipunctata
ies	Animalia	Arthropoda Hexapoda	Insecta Pterygota	Paleoptera Ephemeroptera	Heptagenioidea Baetidae	Baetis (Acentrella)	Spp
ater p	Animalia	Arthropoda Crustacea	Malacostraca Eumalacostraca	Syncarida Amphipoda Gammaridae	Gammaridae	Gammarus Rivulo- gammarus	pulex
*	Animalia	Arthropoda	Insecta	Diptera	V.A.T.T	Chironomidae	Spp
iting s	Animalia	Arthropoda Hexapoda	Insecta Pterygota	Neoptera Diptera Nematocerca Culicomorpha	Chironomidae	Chironomus	Spp.
Fly	Animalia	Arthropoda Hexapoda	Insecta Pterygota	Neoptera Megaloptera	Sialidae	Sialis	lutaria
Fly	Animalia	Arthropoda Hexapoda	Insecta Pterygota	Neoptera Diptera Nematocerca Culicomorpha	Simuliidae Simuliinae Simuliini-tribe	Simulium (Eusimulium)	Spp.
Louse	Animalia	Arthropoda Crustacea	Malacostraca Eumalacostraca	Syncarida Isopoda Asellota	Asellidae	Asellus	Spp.
agell	Plantae	Euglenophycota Mastigophora	Euglenophyceae	Euglenales	Euglenaceae	Euglena	Spp.
iting	Animalia	Arthropoda	Insecta	Diptera	Limnophidae	Limnophyes	Spp.

Classification of Traditional Water Treatment Protozoa*

Appendix Table 2

Superclass	Class	Order	Genus	Species	Ref	Percolating	Activated	Imhoff Tanks
Mastigophora	Phytomastigoph	Chrysomonadid	Anthophysa	vegetans	Muller	Yes	Yes	Yes
Mastigophora	Phytomastigoph	Chrysomonadid	Monas	amoebina	Meyer	Yes	No	Yes
Mastigophora	Phytomastigoph	Chrysomonadid	Monas	fluida	Dujardin	Yes	Yes	No
Mastigophora	Phytomastigoph	Chrysomonadid	Monas	minima	Meyer	Yes	Yes	Yes
Mastigophora	Phytomastigoph	Chrysomonadid	Monas	obliqua	Schewiakoff	Yes	Yes	No
Mastigophora	Phytomastigoph	Chrysomonadid	Monas	vestita	Kent	No	Yes	No
Mastigophora	Phytomastigoph	Chrysomonadid	Monas	vivipara	Ehrenberg	Yes	No	No
Mastigophora	Phytomastigoph	Chrysomonadid	Monas	vulgaris	Cienkowski	Yes	No	No
Mastigophora	Phytomastigoph	Chrysomonadid	Oicomonas	mutabilis	Kent	Yes	No	No
Mastigophora	Phytomastigoph	Chrysomonadid	Oicomonas	ocellata	Scherfel	No	Yes	No
Mastigophora	Phytomastigoph	Chrysomonadid	Oicomonas	socialis	Moroff	Yes	Yes	Yes
Mastigophora	Phytomastigoph	Chrysomonadid	Oicomonas	steinii	Kent	Yes	Yes	No
Mastigophora	Phytomastigoph	Chrysomonadid	Oicomonas	terno	Ehrenberg	Yes	Yes	Yes
Mastigophora	Phytomastigoph	Chrysomonadid	Stylobyron	petiolatum	Dujardin	Yes	No	No
Mastigophora	Phytomastigoph	Chrysomonadid	Synura	uvella	Ehrenberg	Yes	Yes	No
Mastigophora	Phytomastigoph	Cryptomonadid	Chilomonas	paramecium	Ehrenberg	Yes	No	Yes
Mastigophora	Phytomastigoph	Cryptomonadid	Cryptomonas	erosa	Ehrenberg	No	Yes	No
Mastigophora	Phytomastigoph	Cryptomonadid	Cryptomonas	ovata	Ehrenberg	No	Yes	No
Mastigophora	Phytomastigoph	Cryptomonadid	Cyathomonas	truncata	Ehrenberg	Yes	Yes	Yes
Mastigophora	Phytomastigoph	Volvocida	Carteria	globosa	Korschikoff	Yes	No	No
Mastigophora	Phytomastigoph	Volvocida	Polytoma	uvella	Ehrenberg	Yes	Yes	Yes
Mastigophora	Phytomastigoph	Euglenida	Anisonema	emarginatum	Stein	Yes	No	No
Mastigophora	Phytomastigoph	Euglenida	Anisonema	grande	Ehrenber	Yes	Yes	No
Mastigophora	Phytomastigoph	Euglenida	Anisonema	ovale	Klebs	Yes	No	No
Mastigophora	Phytomastigoph	Euglenida	Anisonema	truncatum	Stein	Yes	No	No
Mastigophora	Phytomastigoph	Euglenida	Astasia	dangeardii	Lemmernan	Yes	No	No
Mastigophora	Phytomastigoph	Euglenida	Astasia	inflata	Dujardin	Yes	No	No
Mastigophora	Phytomastigoph	Euglenida	Astasia	quartana	Moroff	Yes	No	No

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Mastigophora	Phytomastigoph	Euglenida	Distigma	proteus	Ehrenberg	Yes	No	Yes
Mastigophora	Phytomastigoph	Euglenida	Entosiphon	sulcatum	Dujardin	Yes	No	Yes
Mastigophora	Phytomastigoph	Euglenida	Euglena	agilis	Carter	Yes	No	No
Mastigophora	Phytomastigoph	Euglenida	Euglena	gracilis	Klebs	No	Yes	No
Mastigophora	Phytomastigoph	Euglenida	Euglena	internedia	Klebs	No	Yes	No
Mastigophora	Phytomastigoph	Euglenida	Euglena	polymorpha	Dangeard	No	Yes	No
Mastigophora	Phytomastigoph	Euglenida	Euglena	viridis	Ehrenberg	Yes	No	No
Mastigophora	Phytomastigoph	Euglenida	Heteronema	acus	Ehrenberg	Yes	Yes	Yes
Mastigophora	Phytomastigoph	Euglenida	Notosolenus	orbicularis	Stokes	Yes	No	Yes
Mastigophora	Phytomastigoph	Euglenida	Peranema	trichophorum	Ehrenberg	Yes	Yes	Yes
Mastigophora	Phytomastigoph	Euglenida	Petalomonas	carinata	France	Yes	No	Yes
Mastigophora	Phytomastigoph	Euglenida	Petalomonas	mediocanellata	Stein	Yes	No	Yes
Mastigophora	Phytomastigoph	Euglenida	Petalomonas	stenii	Klebs	Yes	No	No
Mastigophora	Phytomastigoph	Euglenida	Rhabdomonas	incurva	Fresnel	Yes	No	No
Mastigophora	Zoomastigophor	Rhizomastigida	Mastigamoeba	radiosa	Lackey	No	No	Yes
Mastigophora	Zoomastigophor	Rhizomastigida	Mastigamoeba	longifilum	Stokes	Yes	No	Yes
Mastigophora	Zoomastigophor	Rhizomastigida	Mastigamoeba	reptans	Stokes	Yes	No	Yes
Mastigophora	Zoomastigophor	Rhizomastigida	Mastigamoeba	viridis	Lackey	No	No	Yes
Mastigophora	Zoomastigophor	Cheanoflagellid	Codosiga	botrytis	Ehrenberg	Yes	Yes	No
Mastigophora	Zoomastigophor	Cheanoflagellid	Monosiga	ovata	Kent	Yes	No	No
Mastigophora	Zoomastigophor	Cheanoflagellid	Monosiga	steinii	Kent	Yes	Yes	No
Mastigophora	Zoomastigophor	Bicoecida	Potertodendron	petiolatum	Stein	Yes	No	No
Mastigophora	Zoomastigophor	Bicoecida	Salpingoeca	amphoridium	Clark	Yes	No	No
Mastigophora	Zoomastigophor	Bicoecida	Salpingoeca	marsonii	Lennerman	No	No	Yes
Mastigophora	Zoomastigophor	Kinetoplastida	Bodo	alexiejffii	Lennermann	Yes	No	Yes
Mastigophora	Zoomastigophor	Kinetoplastida	Bodo	angustus	Dujardin	Yes	Yes	Yes
Mastigophora	Zoomastigophor	Kinetoplastida	Bodo	caudatus	Dujardin	Yes	Yes	Yes
Mastigophora	Zoomastigophor	Kinetoplastida	Bodo	edax	Klebs	Yes	Yes	No
Mastigophora	Zoomastigophor	Kinetoplastida	Bodo	glissans	Lackey	Yes	No	Yes
Mastigophora	Zoomastigophor	Kinetoplastida	Bodo	globosus	Stein	Yes	Yes	No
Mastigophora	Zoomastigophor	Kinetoplastida	Bodo	lens	Muller	Yes	Yes	Yes
Mastigophora	Zoomastigophor	Kinetoplastida	Bodo	mutabilis	Klebs	Yes	Yes	No

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Mastigophora	Zoomastigophor	Kinetoplastida	Bodo	putrinus	Stokes	Yes	No	Yes
Mastigophora	Zoomastigophor	Kinetoplastida	Bodo	saltans	Ehrenberg	Yes	Yes	No
Mastigophora	Zoomastigophor	Kinetoplastida	Cercobodo	crassicauda	Alexieff	Yes	Yes	Yes
Mastigophora	Zoomastigophor	Kinetoplastida	Cercobodo	longicauda	Stein	Yes	Yes	Yes
Mastigophora	Zoomastigophor	Kinetoplastida	Cercobodo	ovatus	Lennerman	Yes	Yes	Yes
Mastigophora	Zoomastigophor	Kinetoplastida	Cercobodo	radiatus	Klebs	Yes	No	No
Mastigophora	Zoomastigophor	Kinetoplastida	Pleuromonas	jaculans	Party	Yes	Yes	Yes
Mastigophora	Zoomastigophor	Kinetoplastida	Rhynchomonas	nasuta	Stokes	Yes	No	No
Sarcodina	Rhizopodea	Amoebida	Amoeba	actinophora	Auerbach	Yes	Yes	No
Sarcodina	Rhizopodea	Amoebida	Amoeba	guttula	Dujardin	Yes	No	Yes
Sarcodina	Rhizopodea	Amoebida	Amoeba	limicola	Rhumbler	No	Yes	No
Sarcodina	Rhizopodea	Amoebida	Amoeba	proteus	Laidy	Yes	Yes	Yes
Sarcodina	Rhizopodea	Amoebida	Amoeba	radiosa	Ehrenberg	Yes	Yes	No
Sarcodina	Rhizopodea	Amoebida	Amoeba	striata	Penard	Yes	Yes	No
Sarcodina	Rhizopodea	Amoebida	Amoeba	verrucosa	Ehrenberg	Yes	Yes	No
Sarcodina	Rhizopodea	Amoebida	Amoeba	vespertilio	Penard	No	Yes	No
Sarcodina	Rhizopodea	Amoebida	Amoeba	villosa	Wallick	Yes	No	No
Sarcodina	Rhizopodea	Amoebida	Hartmannella	hyalina	Dangeard	Yes	Yes	Yes
Sarcodina	Rhizopodea	Amoebida	Naegleria	gruberi	Schardinger	Yes	No	Yes
Sarcodina	Rhizopodea	Amoebida	Vahlkampffia	albida	Dujardin	Yes	Yes	Yes
Sarcodina	Rhizopodea	Amoebida	Vahlkampffia	fragilis	Lackey	No	No	Yes
Sarcodina	Rhizopodea	Amoebida	Vahlkampffia	limax	Dujardin	Yes	Yes	Yes
Sarcodina	Rhizopodea	Amoebida	Vahlkampffia	minuta		Yes	No	No
Sarcodina	Rhizopodea	Amoebida	Arcella	discoides	Ehrenberg	Yes	Yes	No
Sarcodina	Rhizopodea	Amoebida	Arcella	dentata	Laidy	Yes	No	No
Sarcodina	Rhizopodea	Amoebida	Arcella	hemisphaerica	Party	Yes	No	No
Sarcodina	Rhizopodea	Amoebida	Arcella	vulgaris	Ehrenberg	Yes	Yes	No
Sarcodina	Rhizopodea	Amoebida	Centropyxis	aculeata	Stein	Yes	Yes	No
Sarcodina	Rhizopodea	Amoebida	Chlamydomorphys	minor	Belar	Yes	Yes	Yes
Sarcodina	Rhizopodea	Amoebida	Chlamydomorphys	stereorea	Cienkowski	Yes	No	Yes
Sarcodina	Rhizopodea	Amoebida	Cochliopodium	bilimbosum	Auerbach	Yes	Yes	No
Sarcodina	Rhizopodea	Amoebida	Cyphoderia	ampulla	Ehrenberg	Yes	No	No

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Sarcodina	Rhizopodea	Arcellinidae	Diffugia	acuminata	Ehrenberg	Yes	No	No
Sarcodina	Rhizopodea	Arcellinidae	Diffugia	constricta	Ehrenberg	No	Yes	No
Sarcodina	Rhizopodea	Arcellinidae	Diffugia	corona	Wallick	Yes	No	No
Sarcodina	Rhizopodea	Arcellinidae	Diffugia	oblonga	Ehrenberg	Yes	Yes	No
Sarcodina	Rhizopodea	Arcellinidae	Diffugia	urceolata	Carter	No	Yes	No
Sarcodina	Rhizopodea	Arcellinidae	Euglypha	alveolata	Dujardin	Yes	No	Yes
Sarcodina	Rhizopodea	Arcellinidae	Euglypha	tuberculata	Dujardin	Yes	Yes	No
Sarcodina	Rhizopodea	Arcellinidae	Hyalosphenia	papillo	Leidy	No	Yes	No
Sarcodina	Rhizopodea	Arcellinidae	Pamphagus	mutabilis	Bailey	Yes	No	No
Sarcodina	Rhizopodea	Arcellinidae	Pseudodiffugia	gracilis	Schlumberger	Yes	Yes	No
Sarcodina	Rhizopodea	Arcellinidae	Trinema	enchelys	Ehrenberg	No	Yes	No
Sarcodina	Rhizopodea	Arcellinidae	Trinema	lineate	Penard	Yes	Yes	Yes
Sarcodina	Actinophryda	Actinophryda	Actinophrys	sol	Ehrenberg	Yes	Yes	No
Sarcodina	Actinophryda	Actinophryda	Actinophrys	vesiculata	Penard	No	Yes	No
Sarcodina	Actinophryda	Actinophryda	Actinosphaeriu	arachnoideum	Penard	No	Yes	No
Sarcodina	Actinophryda	Actinophryda	Actinosphaeriu	eichhorni	Penard	Yes	Yes	No
Sarcodina	Actinophryda	Actinophryda	Heterophrys	glabrescens	Penard	No	Yes	No
Sarcodina	Actinophryda	Actinophryda	Heterophrys	myriopoda	Archer	Yes	Yes	No
Sarcodina	Actinophryda	Actinophryda	Raphidiophrys	elegans	Hertwig &	Yes	No	No
Sarcodina	Proteomyxida	Proteomyxida	Hyalodiscus	rubicundus	Hertwig &	Yes	No	No
Sarcodina	Proteomyxida	Proteomyxida	Nuclearia	simplex	Cienkowski	Yes	No	No
Sarcodina	Proteomyxida	Proteomyxida	Vampyrella	lateritia	Fresenius	Yes	No	No
	Ciliata	Gymnostomatid	Amphileptus	claparedei	Stein	Yes	Yes	No
	Ciliata	Gymnostomatid	Coleps	bicuspid	Noland	No	Yes	No
	Ciliata	Gymnostomatid	Coleps	elongatus	Ehrenberg	No	Yes	No
	Ciliata	Gymnostomatid	Coleps	hirtus	Nitzsch	Yes	Yes	No
	Ciliata	Gymnostomatid	Chaenea	terres	Dujardin	Yes	Yes	No
	Ciliata	Gymnostomatid	Didinium	nasutum	Muller	Yes	Yes	No
	Ciliata	Gymnostomatid	Dileptus	anser	Muller	Yes	No	No
	Ciliata	Gymnostomatid	Enchelys	curvilata	Smith	No	Yes	No
	Ciliata	Gymnostomatid	Enchelys	simplex	Kahl	Yes	No	No
	Ciliata	Gymnostomatid	Enchelyomorph	vermicularis	Smith	Yes	Yes	No

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Ciliata	Gymnostomatid	Hemiphrys	branchiarum	Wenrich	No	Yes	No
Ciliata	Gymnostomatid	Hemiphrys	fusidens	Kahl	Yes	Yes	No
Ciliata	Gymnostomatid	Hemiphrys	pleurosigma	Stokes	Yes	Yes	No
Ciliata	Gymnostomatid	Litonotus	anguilla	Kahl	No	Yes	No
Ciliata	Gymnostomatid	Litonotus	carinatus	Stokes	Yes	Yes	No
Ciliata	Gymnostomatid	Litonotus	cygnus	Muller	Yes	Yes	No
Ciliata	Gymnostomatid	Litonotus	fasciola	Ehr-	Yes	Yes	Yes
Ciliata	Gymnostomatid	Litonotus	lamella	Schewiakoff	Yes	Yes	Yes
Ciliata	Gymnostomatid	Loxodes	rostrum	Muller	Yes	No	No
Ciliata	Gymnostomatid	Loxophyllum	helus	Stokes	No	Yes	No
Ciliata	Gymnostomatid	Loxophyllum	meleagris	Dujardin	Yes	No	No
Ciliata	Gymnostomatid	Loxophyllum	multinucleatum	Kahl	No	Yes	No
Ciliata	Gymnostomatid	Prorodon	armatus	Clap. &	Yes	No	No
Ciliata	Gymnostomatid	Prorodon	discolor	Ehr-	No	Yes	No
Ciliata	Gymnostomatid	Prorodon	griseus	Clap. &	Yes	No	No
Ciliata	Gymnostomatid	Prorodon	teres	Ehrenberg	Yes	No	No
Ciliata	Gymnostomatid	Rhopalodophyllum	crassa	Kahl	Yes	No	No
Ciliata	Gymnostomatid	Spathidium	hyallum	Dujardin	No	Yes	No
Ciliata	Gymnostomatid	Spathidium	spathula	Muller	Yes	Yes	No
Ciliata	Gymnostomatid	Trachelophyllum	clavatum	Stokes	No	Yes	No
Ciliata	Gymnostomatid	Trachelophyllum	pusillum	Perty-Clap. &	Yes	Yes	No
Ciliata	Gymnostomatid	Urotrichia	farcta	Clap. &	Yes	No	No
Ciliata	Gymnostomatid	Chilodonella	cucullulus	Muller	Yes	Yes	No
Ciliata	Gymnostomatid	Chilodonella	fluvialis	Stokes	No	Yes	No
Ciliata	Gymnostomatid	Chilodonella	uniclata	Ehrenberg	Yes	Yes	No
Ciliata	Gymnostomatid	Dysteria	fluvialis	Stein	No	Yes	No
Ciliata	Gymnostomatid	Orthodonella	gutta	Cohn	Yes	Yes	No
Ciliata	Gymnostomatid	Trochilia	minuta	Roux	Yes	Yes	No
Ciliata	Trichostomatida	Colpoda	aspera	Kahl	Yes	Yes	No
Ciliata	Trichostomatida	Colpoda	cucullus	Muller	Yes	Yes	No
Ciliata	Trichostomatida	Colpoda	inflata	Stokes	Yes	Yes	Yes
Ciliata	Trichostomatida	Colpoda	steinii	Maupas	Yes	Yes	Yes

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Ciliata	Trichostomatida	Drepanomonas	revoluta	Penard	No	Yes	No
Ciliata	Trichostomatida	Plagiopyla	nasuta	Stein	Yes	Yes	Yes
Ciliata	Trichostomatida	Trichopelma	opaca	Penard	Yes	No	No
Ciliata	Trichostomatida	Trimyema	compressum	Lackey	Yes	No	Yes
Ciliata	Trichostomatida	Trimyema	pura	Ehrenberg	Yes	Yes	No
Ciliata	Hymenostomati	Cohnlembus	pusillus	Kahl	Yes	No	No
Ciliata	Hymenostomati	Cohnlembus	verminus	Muller	Yes	No	No
Ciliata	Hymenostomati	Colpidium	campylum	Stokes	Yes	Yes	No
Ciliata	Hymenostomati	Colpidium	colpoda	Stein	Yes	Yes	No
Ciliata	Hymenostomati	Colpidium	striatum	Stokes	Yes	No	No
Ciliata	Hymenostomati	Glaucoma	scintillans	Ehrenberg	Yes	Yes	Yes
Ciliata	Hymenostomati	Loxopcephalus	granulosus	Kent	Yes	Yes	No
Ciliata	Hymenostomati	Pseudoglaucoma	muscorum	Kahl	Yes	Yes	No
Ciliata	Hymenostomati	Sathrophilus	oviformis	Kahl	No	Yes	No
Ciliata	Hymenostomati	Tetrahymena	pyriformis	Ehrenberg	Yes	Yes	No
Ciliata	Trichostomatida	Tetrahymena	rostrata	Kahl	No	Yes	No
Ciliata	Hymenostomati	Tetrahymena	vorax	Kidder	No	Yes	No
Ciliata	Hymenostomati	Uronema	nigricans		Yes	Yes	No
Ciliata	Hymenostomati	Cinctochilum	margaritaceum	Perty	Yes	Yes	Yes
Ciliata	Hymenostomati	Paramecium	aurelia	Ehrenberg	Yes	Yes	No
Ciliata	Hymenostomati	Paramecium	bursaria	Ehrenberg	Yes	Yes	No
Ciliata	Hymenostomati	Paramecium	caudatum	Ehrenberg	Yes	Yes	No
Ciliata	Hymenostomati	Paramecium	putrinum	Clap. &	Yes	Yes	Yes
Ciliata	Hymenostomati	Paramecium	trichium	Stokes	Yes	No	No
Ciliata	Hymenostomati	Urocentrum	turbo	Muller	Yes	No	No
Ciliata	Hymenostomati	Cyclidium	citrullus	Cohn	No	Yes	No
Ciliata	Hymenostomati	Cyclidium	glaucoma	Muller	Yes	Yes	Yes
Ciliata	Hymenostomati	Cyclidium	lanuginosum	Penard	Yes	No	No
Ciliata	Hymenostomati	Cyclidium	oblongum	Kahl	Yes	No	No
Ciliata	Hymenostomati	Pleurogonema	crassum	Dujardin	Yes	No	No
Ciliata	Peritrichida	Carchesium	polypinum	Linnaeus	Yes	Yes	No
Ciliata	Peritrichida	Epistylis	anastatica	Linne	No	Yes	No

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Ciliatea	Peritrichida	Epistylis	articulata	Fromental	No	Yes	No
Ciliatea	Peritrichida	Epistylis	cambari	Kellicott	No	Yes	No
Ciliatea	Peritrichida	Epistylis	elongata	Stokes	No	Yes	No
Ciliatea	Peritrichida	Epistylis	lacustris	Imhoff	No	Yes	No
Ciliatea	Peritrichida	Epistylis	plicatilis	Ehrenberg	Yes	Yes	No
Ciliatea	Peritrichida	Epistylis	pyriformis	d'Udekem	No	Yes	No
Ciliatea	Peritrichida	Epistylis	rotans	Svec	Yes	Yes	No
Ciliatea	Peritrichida	Epistylis	umbilicata	Clap. &	No	Yes	No
Ciliatea	Peritrichida	Opercularia	asellicola	Kahl	No	Yes	No
Ciliatea	Peritrichida	Opercularia	berberina	Laine	Yes	Yes	Yes
Ciliatea	Peritrichida	Opercularia	coarctata	Clap. &	Yes	Yes	No
Ciliatea	Peritrichida	Opercularia	curvicaula	Penard	Yes	Yes	No
Ciliatea	Peritrichida	Opercularia	glomerata	Roux	No	Yes	No
Ciliatea	Peritrichida	Opercularia	microdiscum	Faure-Fremiet	Yes	Yes	No
Ciliatea	Peritrichida	Opercularia	minima	Kahl	Yes	Yes	No
Ciliatea	Peritrichida	Opercularia	phryganeae	Kahl	Yes	No	No
Ciliatea	Peritrichida	Opercularia	plicatilis	Stokes	Yes	No	No
Ciliatea	Peritrichida	Platycola	decumbens	Ehrenberg	Yes	No	No
Ciliatea	Peritrichida	Pyxicola	socialis	Gruber	Yes	No	No
Ciliatea	Peritrichida	Pyxidiella	collare	Kahl	No	Yes	No
Ciliatea	Peritrichida	Pyxidiella	hennequyi	Faure-Fremiet	No	Yes	No
Ciliatea	Peritrichida	Pyxidiella	invaginatum	Stokes	No	Yes	No
Ciliatea	Peritrichida	Pyxidiella	urceolatum	Stokes	No	Yes	No
Ciliatea	Peritrichida	Pyxidiella	vernale	Stokes	No	Yes	No
Ciliatea	Peritrichida	Rhabdosyla	inclians	Kahl	No	Yes	No
Ciliatea	Peritrichida	Rhabdosyla	pyriformis	Muller	Yes	No	No
Ciliatea	Peritrichida	Rhabdosyla	vernalis	Party	No	Yes	No
Ciliatea	Peritrichida	Telotrochidium	hennequyi	Faure-Fremiet	No	Yes	No
Ciliatea	Peritrichida	Vaginicola	crystallina	Ehrenberg	No	Yes	No
Ciliatea	Peritrichida	Vaginicola	striata	Fromental	Yes	Yes	No
Ciliatea	Peritrichida	Vaginicola	tincta	Ehrenberg	Yes	No	No
Ciliatea	Peritrichida	Vorticella	aquilata	Kahl	Yes	Yes	No

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Ciliatea	Peritrichida	Vorticella	alba	Fromentel	Yes	Yes	No
Ciliatea	Peritrichida	Vorticella	campanula	Ehrenberg	Yes	Yes	No
Ciliatea	Peritrichida	Vorticella	communis	Fromentel	Yes	Yes	No
Ciliatea	Peritrichida	Vorticella	convallaria	Linnæus	Yes	Yes	Yes
Ciliatea	Peritrichida	Vorticella	elongata	Fromentel	Yes	Yes	No
Ciliatea	Peritrichida	Vorticella	extensa	Kahl	No	Yes	No
Ciliatea	Peritrichida	Vorticella	fronteli	Kahl	Yes	Yes	No
Ciliatea	Peritrichida	Vorticella	hamata	Ehrenberg	Yes	No	No
Ciliatea	Peritrichida	Vorticella	longijilum	Kent	No	Yes	No
Ciliatea	Peritrichida	Vorticella	microstoma	Ehrenberg	Yes	Yes	Yes
Ciliatea	Peritrichida	Vorticella	monilata	Tatem	No	Yes	No
Ciliatea	Peritrichida	Vorticella	muralis	Penard	No	Yes	No
Ciliatea	Peritrichida	Vorticella	nebulifera/simili	Stokes	Yes	Yes	No
Ciliatea	Peritrichida	Vorticella	nutans	Muller	No	Yes	No
Ciliatea	Peritrichida	Vorticella	picta	Ehrenberger	No	Yes	No
Ciliatea	Peritrichida	Vorticella	punctata	Dons	No	Yes	No
Ciliatea	Peritrichida	Vorticella	pusilla	Muller	No	Yes	No
Ciliatea	Peritrichida	Vorticella	putrina	Muller-Kent	No	Yes	No
Ciliatea	Peritrichida	Vorticella	pyrum	Mareschkowsky	No	Yes	No
Ciliatea	Peritrichida	Vorticella	striata/octava	Stokes	Yes	Yes	No
Ciliatea	Peritrichida	Vorticella	submicrostoma	Ghosh	No	Yes	No
Ciliatea	Peritrichida	Vorticella	vernalis	Stokes	No	Yes	No
Ciliatea	Peritrichida	Vorticella	aselii	Clap. & Entz	No	Yes	No
Ciliatea	Peritrichida	Zoothamnium	mucedo	Entz	Yes	Yes	No
Ciliatea	Peritrichida	Zoothamnium	pygmaeum	d'Udekent	No	Yes	No
Ciliatea	Peritrichida	Zoothamnium	persicinum	Party	No	Yes	No
Ciliatea	Heterotrichida	Blepharisma	undulans	Stein	Yes	Yes	No
Ciliatea	Heterotrichida	Climacostomum	virens	Ehrenberg	No	Yes	No
Ciliatea	Heterotrichida	Metopus	es	Muller	Yes	Yes	No
Ciliatea	Heterotrichida	Metopus	signoides	Clap. & Kahl	No	No	Yes
Ciliatea	Heterotrichida	Metopus	setosus	Kahl	No	Yes	No
Ciliatea	Heterotrichida	Spirostomum	ambiguum	Muller-	Yes	Yes	No

Appendix Table 2

Ciliata	Heterotrichida	Spirostrum	ambiguum/mino	Roux	Yes	No	No
Ciliata	Heterotrichida	Spirostrum	intermedium	Kahl	Yes	No	No
Ciliata	Heterotrichida	Spirostrum	teres	Clap. &	Yes	No	No
Ciliata	Heterotrichida	Stentor	igneus	Ehrenberg	No	Yes	No
Ciliata	Heterotrichida	Stentor	multiformis	Muller	No	Yes	No
Ciliata	Heterotrichida	Stentor	polymorphus	Muller	Yes	Yes	No
Ciliata	Heterotrichida	Stentor	roesei	Ehrenberg	Yes	Yes	No
Ciliata	Oligotrichida	Halteria	granclinnella	Muller	Yes	No	No
Ciliata	Odontostomatid	Saprodinium	putrinum	Lackey	Yes	No	No
Ciliata	Hypotrichida	Aspidisca	costata	Dujardin	Yes	Yes	Yes
Ciliata	Hypotrichida	Aspidisca	lynceus	Ehrenberg	Yes	Yes	No
Ciliata	Hypotrichida	Aspidisca	polystyla	Stein	No	Yes	No
Ciliata	Hypotrichida	Aspidisca	sulcata	Kahl	No	Yes	No
Ciliata	Hypotrichida	Aspidisca	turrita	Ehrenberg	Yes	Yes	No
Ciliata	Hypotrichida	Euplotes	aediculatus	Pierson	No	Yes	No
Ciliata	Hypotrichida	Euplotes	affinis/typica	Dujardin	Yes	Yes	No
Ciliata	Hypotrichida	Euplotes	carinatus	Stokes	No	Yes	No
Ciliata	Hypotrichida	Euplotes	charon	Muller	Yes	Yes	No
Ciliata	Hypotrichida	Euplotes	eurytomus	Wrzesniowski	Yes	Yes	No
Ciliata	Hypotrichida	Euplotes	harpa	Stein	Yes	No	No
Ciliata	Hypotrichida	Euplotes	moebiusi/quadri	Kahl	Yes	Yes	No
Ciliata	Hypotrichida	Euplotes	patella	Muller	Yes	Yes	No
Ciliata	Hypotrichida	Euplotes	patella f. latus	Kahl	No	Yes	No
Ciliata	Hypotrichida	Euplotes	Patella f. ...	Stokes	No	Yes	No
Ciliata	Hypotrichida	Histriculus	similis	Corliss	Yes	Yes	No
Ciliata	Hypotrichida	Histriculus	vorax	Corliss	Yes	Yes	No
Ciliata	Hypotrichida	Holosticha	hymenophora	Stokes	No	Yes	No
Ciliata	Hypotrichida	Holosticha	vernalis	Stokes	No	Yes	No
Ciliata	Hypotrichida	Opisthotricha	similis	Engelmann	Yes	Yes	No
Ciliata	Hypotrichida	Oxytricha	fallax	Stein	Yes	Yes	No
Ciliata	Hypotrichida	Oxytricha	ludibunda	Stokes	Yes	Yes	No
Ciliata	Hypotrichida	Stylonychia	mytilus	Ehrenberg	Yes	Yes	No

Appendix Table 2

Ciliata	Hypotrichida	Stylonychia	pustulata	Ehrenberg	Yes	Yes	No
Ciliata	Hypotrichida	Stylonychia	putrina	Stokes	No	Yes	No
Ciliata	Hypotrichida	Tachysoma	parvistyla	Stokes	No	Yes	No
Ciliata	Hypotrichida	Tachysoma	pellionella	Muller-Stein	Yes	Yes	No
Ciliata	Hypotrichida	Uroleptus	limnetis	Stokes	No	Yes	No
Ciliata	Hypotrichida	Uroleptus	longicaudatus	Stokes	No	Yes	No
Ciliata	Hypotrichida	Uroleptus	musculus	Muller	Yes	No	No
Ciliata	Hypotrichida	Uroleptus	piscis	Muller	Yes	No	No
Ciliata	Hypotrichida	Urostyla	weissei	Stein	Yes	No	No
Ciliata		Acineta	cuspidata	Stokes	No	Yes	No
Ciliata		Acineta	granilis	Kent	No	Yes	No
Ciliata		Acineta	foetida	Maupas	Yes	Yes	No
Ciliata		Acineta	tuberosa	Ehrenberg	No	Yes	No
Ciliata		Discophyra	elongata	Clap. &	No	Yes	No
Ciliata		Podophyra	carchesii	Clap. &	No	Yes	No
Ciliata		Podophyra	elongata	Wailles	No	Yes	No
Ciliata		Podophyra	fixa	Quennerstedt	Yes	Yes	No
Ciliata		Podophyra	maupasi	Butschli	Yes	Yes	No
Ciliata		Sphaerophyra	magna	Maupas	Yes	Yes	No
Ciliata		Sphaerophyra	pusilla	Clap. &	No	Yes	No
Ciliata		Thecacneta	cothurnoides	Collin	No	Yes	No
Ciliata		Tokophrya	cycloplum	Clap. &	No	No	No
Ciliata		Tokophrya	infusionem	Stein	No	Yes	No
Ciliata		Tokophrya	mollis	Butschli	Yes	Yes	No
Ciliata		Tokophrya	quadrupartita	Clap. &	No	Yes	No
Ciliata					No	No	No

Appendix Table 3

Saprobic Classification of Common Indicator Organisms

Description	Organism	Genus	Species	Water Quality Class	Pollution Level	Quality
Armour Plated	Dinoflagellate	<i>Ceratium</i>	<i>hirundinella</i>	Oligosaprobic	Nil-Slight	1
Green	Alga	<i>Hydrodictyon</i>	<i>reticulatum</i>	"	"	1
Alternate-Flowered	Water-Milfoil	<i>Myriophyllum</i>	<i>alterniflorum</i>	"	"	1
Pond weed		<i>Potamogeton</i>	<i>nitens</i>	"	"	1
Najadaceae		<i>Najas</i>	<i>intermedia</i>	"	"	1
"Wheel animalcule"	Rotifer	<i>Nassula</i>	<i>gracilis</i>	"	"	1
"Bell animalcule"		<i>Vorticella</i>	<i>similis</i>	"	"	1
Free-living	turbellarian	<i>Dugesia</i>	<i>gonocephala</i>	"	"	1
"Wheel animalcule"	Rotifer	<i>Conochilus</i>	<i>unicornis</i>	"	"	1
Water	Flea	<i>Sida</i>	<i>crystallina</i>	"	"	1
Water	Flea	<i>Holopedium</i>	<i>gibberum</i>	"	"	1
Buff-Head	Cottidae	<i>Comus</i>	<i>peocilopus</i>	"	"	1
Euglenoid	Flagellate	<i>Phacus</i>	<i>pleuronectes</i>	B-Mesosaprobic	Moderate	2
Green	Alga	<i>Eudorina</i>	<i>elegans</i>	"	"	2
Yellow	Water- Lily	<i>Nuphar</i>	<i>lutea</i>	"	"	2
Water	Chestnut	<i>Trapa</i>	<i>natans</i>	"	"	2
Starwort		<i>Callitriche</i>		"	"	2
Broad-leaved	Pondweed	<i>Potamogeton</i>	<i>natans</i>	"	"	2
"Sun animalcule"	Heliozoan	<i>Actinosphaeriu</i>	<i>bursaria</i>	"	"	2
"Slipper animalcule"	Paramecium	<i>Paramecium</i>	<i>bursaria</i>	"	"	2
"Wheel animalcule"	Rotifer	<i>Brachionus</i>	<i>urceolaris</i>	"	"	2
Wheel animalcule	Rotifer	<i>Keratella</i>	<i>quadrata</i>	"	"	2
Wheel animalcule	Rotifer	<i>Keratella</i>	<i>cochlearis</i>	"	"	2
Wheel animalcule	Rotifer	<i>Polyarthra</i>	<i>vulgaris</i>	"	"	2
Wheel animalcule	Rotifer	<i>Stephanocerus</i>	<i>fimbriatus</i>	"	"	2
Segmented Worm	Oligochaete	<i>Aelosoma</i>	<i>hemprichi</i>	"	"	2
Segmented Worm	Oligochaete	<i>Stylaria</i>	<i>lacustris</i>	"	"	2
Leech		<i>Glossiphonia</i>	<i>complanata</i>	"	"	2
Great	Fresh Snail	<i>Lymnaea</i>	<i>stagnalis</i>	"	"	2
Zebra	Mussel	<i>Dreissena</i>	<i>polymorpha</i>	"	"	2
Roach		<i>Rutilus</i>	<i>rutilus</i>	"	"	2
Perch		<i>Perca</i>	<i>fluviatilis</i>	"	"	3
Euglenoid	Flagellate	<i>Pacus</i>	<i>longicauda</i>	a-Mesosaprobic	Heavily	3
Green	Alga	<i>Spondylomorom</i>	<i>quaternarium</i>	"	"	3
Hornwort		<i>Ceratophyllum</i>	<i>demersum</i>	"	"	3
Fennel-leaved	Pondweed	<i>Potamogeton</i>	<i>pectinatus</i>	"	"	3
Sun animalcule	Heliozoan	<i>Actinophrys</i>	<i>sol</i>	"	"	3
Ciliate		<i>Spirostomum</i>	<i>ambiguum</i>	"	"	3
Ciliate		<i>Stenor</i>	<i>coeruleus</i>	"	"	3
Wheel animalcule	Rotifer	<i>Epiphanes</i>	<i>senta</i>	"	"	3
Wheel animalcule	Rotifer	<i>Brachionus</i>	<i>rubens</i>	"	"	3

Leech		<i>Herpobdella</i>	<i>octoculata</i>	"	"	3
Water	Flea	<i>Daphnia</i>	<i>magna</i>	"	"	3
Water	Flea	<i>Daphnia</i>	<i>pulex</i>	"	"	3
Water	Flea	<i>Moina</i>	<i>brachiata</i>	"	"	3
Water	Louse	<i>Aseillus</i>	<i>aquaticus</i>	"	"	3
Red Sulphur	Bacterium	<i>Chromatium</i>	<i>minutissimum</i>	Polysaprobic	Extreme Pollution	4
Red Sulphur	Bacterium	<i>Chromatium</i>	<i>okenii</i>	"	"	4
Red Sulphur	Bacterium	<i>Chromatium</i>	<i>vinosum</i>	"	"	4
Sulphur	Bacterium	<i>Beggiatoa</i>		"	"	4
Ciliate		<i>Colpidium</i>	<i>colpoda</i>	"	"	4
Bell animalcule		<i>Vorticella</i>	<i>microstoma</i>	"	"	4
Wheel animalcule	Rotifer	<i>Rotaria</i>	<i>neptunia</i>	"	"	4
Segmented Worm	Oligochaete	<i>Tubifex</i>	<i>tubifex</i>	"	"	4
Red-tailed	Maggot/larva	<i>Eristalis</i>	<i>tenax</i>	"	"	4
Blood-worm	Maggot/larva	<i>Chironomus</i>		"	"	4

Appendix Table 4

Main Category	Sub Category	Class	Order	Family	Genus	Species	Common Name	Named By	Location 1	Use 1	Use 2
Aquatic Plants	Green Algae	Chlorophyceae/yta	Chlorococcales	Cocystaceae	Chorella	ellipsoidae		Gerneck	America	Human Food	Fish cult. Food
Aquatic Plants	Green Algae	Chlorophyta	Chlorococcales	Cocystaceae	Chlorella	pyrenoidosa		Chick	Widely distributed	Human Food	Fish cult. Food
Aquatic Plants	Green Algae	Chlorophyta	Chlorococcales	Cocystaceae	Chlorella	vulgaris		Beijernick	Widely Distributed	Human Food	Fish Cult. Food
Cyanobacteria	Blue/Green Algae	Myxophyta	Chroococcales	Chroococcaceae	Coccolithis	aeruginosa	Nageli	Drout & Daily	Japan	oxygenation	Eel ponds
Algae	Diatom	Bacillariophyta	Centrales	Skeletonemaceae	Nitzschia	clesterium	Ehrenberg	Smith	Widely Distributed	Oyster Feed	
Aquatic Plants	Green Algae	Chlorophyta	Chlorococcales	Scenedesmaceae	Scenedesmus	obliquus	Turpin	Kuetz	Widely Distributed	Feed test animals	i.e. goldfish,albino rats
Cyanobacteria	Blue/Green Algae	Myxophyta	Chroococcales	Nostocales	Oscillatoriaceae	Spirulina		Seth & Gardner	European Coasts		
Angiosperm	Monocotyledon			Lemnaceae	Wolffia	sp.	Duck Weed		Widely Distributed	Fish culture	Grass Carp food
Aquatic Animals	Porifera	Demospongiae	Monaxonida	Spongillidae	Spongilla	spp.	Sponges		Widely Distributed	Experimental	
Aquatic Animals	Rotifera	Monogononta	Ploima	Branchionidae	Branchionus	calyciflorus	Wheel animalcule	Pallas	Widely distributed	Fish food	eat algae & bacteria
Aquatic Animals	Rotifera	Monogononta	Ploima	Branchionidae	Branchionus	plicatilis	Wheel animalcule	Muller	Widely Distributed	Fist food	Prawn food
Aquatic Animals	Rotifera	Monogononta	Ploima	Branchionidae	Branchionus	rubens	Wheel animalcule	Ehrenberg	Widely Distributed		
Aquatic Animals	Arthropoda	Crustacea	Branchiopoda	Cladocera	Chydorus	sphaericus	Water Flea	Muller	Widely Distributed		
Aquatic Animals	Arthropoda	Crustacea	Branchiopoda	Daphnidae	Daphnia	carinata	Water Flea	King	Widely Distributed	Fish food	e.g. Sturgeon
Aquatic Animals	Arthropoda	Crustacea	Branchiopoda	Daphnidae	Daphnia	magna	Water Flea	Straus	Widel Distributed	Fish food	e.g. Sturgeon
Aquatic Animals	Arthropoda	Crustacea	Branchiopoda	Daphnidae	Daphnia	pulex	Water Flea	Leydig	Widely Distributed	Fish Food	e.g. Sturgeon
Aquatic Animals	Arthropoda	Crustacea	Branchiopoda	Daphnidae	Daphnia	sp.	Water Flea		Widely Distributed	Fish food	
Aquatic Animal	Arthropoda	Crustacea	Branchiopoda	Daphnidae	Moina	macrocopa	Water Flea	Straus	Widely distributed	Live fish larvae food	White fish
Aquatic Animals	Arthropoda	Crustacea	Branchiopoda	Daphnidae	Moina	spp.	Water Flea		Widely Distributed	Fish food	
Aquatic Animals	Arthropoda	Crustacea	Branchiopoda	Polyphemidae	Polyphemus	pediculus	Water Flea	Linnaeus	N. America	Feed muskellenge	fry
Aquatic Animals	Arthropoda	Crustacea	Branchiopoda	Daphnidae	Simocephalus	spp.	Water Flea		Russia	Fish food	Namely Sturgeon
Aquatic Animal	Arthropoda	Crustacea	Amphipoda	Gammaridae	Gammarus	spp.	Shrimp		Japan	Carp food	
Aquatic Animals	Arthropoda	Crustacea	Decapoda	Astacidae	Astacus	spp.	FW Crayfish		Widely Distributed	Food	
Aquatic Animals	Arthropoda	Crustacea	Decapoda	Atyidae	Cardina	gracilirostris	Shrimp	De Man	India	Food	
Aquatic Animals	Arthropoda	Crustacea	Decapoda	Palaemonidae	Macrobrachium	acanthurus	FW Shrimp	Wiegmann	N.America	Food	
Aquatic Animals	Arthropoda	Crustacea	Decapoda	Palaemonidae	Macrobrachium	americanum	FW Prawn	Bate	Pacific states	Food	
Aquatic Animals	Arthropoda	Crustacea	Decapoda	Palaemonidae	Macrobrachium	carcinus	FW Shrimp	Linnaeus	Exp. Florida	Food	
Aquatic Animals	Arthropoda	Crustacea	Decapoda	Palaemonidae	Macrobrachium	idae	Shrimp	Heller	Indo-West pacific	Food	
Aquatic Animals	Arthropoda	Crustacea	Decapoda	Palaemonidae	Macrobrachium	lanchesteri	FW Shrimp	De Man	Thailand	Food	
Aquatic Animals	Arthropoda	Crustacea	Decapoda	Palaemonidae	Macrobrachium	malcolmsonii	Shrimp	Milne Edwards	India	Food	
Aquatic Animals	Arthropoda	Crustacea	Decapoda	Palaemonidae	Macrobrachium	rosenbergii	Giant FW Prawn	De Man	Indo-Pacific	Food	
Aquatic Animals	Arthropoda	Crustacea	Decapoda	Palaemonidae	Macrobrachium	rude	FW Prawn	Heller	E.Africa	Food	
Aquatic Animals	Arthropoda	Crustacea	Decapoda	Palaemonidae	Macrobrachium	sintangense	FW Shrimp	De Man	S.E. Asia	Food	
Aquatic Animals	Arthropoda	Crustacea	Decapoda	Astacidae	Oronectes	propinquus	Cray Fish	Girard	N. America	Food for fishes	
Aquatic Animals	Arthropoda	Crustacea	Decapoda	Astacidae	Pacifastacus	leniusculus	Cray Fish	Dana	N.America	stocking in Finland	food
Aquatic Animals	Arthropoda	Crustacea	Decapoda	Palaemonidae	Palaemon	paucidens	Prawn	De Haan	Japan	Food	
Aquatic Animals	Arthropoda	Crustacea	Decapoda	Palaemonidae	Palaemon	styliferus	Prawn	Milne Edwards	India-Thailand	Food	

Appendix Table 4

Aquatic Animals	Arthropoda	Crustacea	Decapoda	Astacidae	Procambarus	clarkii	Red Swamp Cray Fish	Girard	N.America	Food	Secondary crop to rice
Aquatic Animals	Arthropoda	Crustacea	Decapoda	Scyllidae	Scylla	serrata	Blue Crab	Forskall	Indo-Pacific	Food	
Aquatic Animals	Arthropoda	Insecta	Diptera	Chironomidae	Chironomus	pucher	Non-biting Midge	Wiedeman	Widely Distributed	Fish Food	e.g. Tilapia
Aquatic Animals	Arthropoda	Insecta	Diptera	Chironomidae	Chironomus	spp.	Non-biting Midge		Europe	Larvae for Fish Food	
Aquatic Animals	Mollusca	Lamellibranchiata	Eulamellibranchs	Unionidae	Lampisilis	clai-borneensis	Mussel	Lea	E.America	Filtering Water	Increasing Fish
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Cyprinidae	Abramis	brama	Bream	Linnaeus	N.W Asia (minor)	Food	Removea detritus
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Acipenseridae	Acipenser	baeri	Siberian sturgeon	Brandt	Siberia	Food	Removal of
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Acipenseridae	Acipenser	guldenstaedti	Russian sturgeon	Brandt	Russia	Food	Removal by juv of,
Aquatic Animals	Vertebrate	Teleostomi	Actinopterygii	Acipenseridae	Acipenser	stellatus	Starred Sturgeon	Pallas	Russia	Food	Removal inverts
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Acipenseridae	Acipenser	ruthenus	Sterlet	Linnaeus	Rumania	Food	
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Cyprinidae	Acrossocheilus	hexagonolepis	Copper Mahseer	McClelland	N.E. India	Esteemed game fish	Food
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Siluridae	Ageniosus	brevifilis	Mandube	Valenciennes	S. America	Tilapia control	
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Characidae	Alestes	imberi		Peters			
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Clupeidae	Alosa	finta	Twaita shad	Cuvier	Morocco	Food	Removal planktonic
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Clupeidae	Alosa	sapidissima	American Shad	Wilson			
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Anguillidae	Anguilla	anguilla	Common River Eel	Linnaeus	Europe, Belgium	Food	Removes aquatic
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Anguillidae	Anguilla	japonica	Japanese Eel	Temminck	Japan, China	Food	
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Cyprinodontidae	Aplocheilus	lineatum	Top Minnow	Valenciennes	India	Food	
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Cyprinodontidae	Aplocheilus	deyi	Ceylon Killifish	Steindachner	Sri Lanka	Food	
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Cyprinodontidae	Aplocheilus	panchax	Blue panchax	Hamilton	India, Pakistan	Food	
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Sciaenidae	Apodinotus	grunniens	FW Drum	Rafinesque	N. America	Food	Removes; mussels
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Arapaimidae	Arapaima	gigas		Cuvier	S.America	Food V tasty	Removes inverts,
Aquatic Animals	vertebrata	Teleostomi	Actinopterygii	Cyprinidae	Aristichthys	nobilis	Big Head	Richardson	S-Central China	Food	Removes
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Cichlidae	Astatoreochromis	aluandi		Pellegrin	Africa, Cameroon,	Billharzia control	shad/coccolacton
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Cichlidae	Astronotus	ocellatus	Apairi	Agassiz in spix	S.America	Food	Eats snails
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Characidae	Astyannax	mexicanus	Banded tetra	Filippi	N. America	Food	
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Atherinidae	Atherinichthys	bonariensis	Peljerrey	Cuvier	Morocco	Food	
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Bagridae	Auchenoglanis	occidentalis		Boulenger	Africa	Food	Omnivorous
Aquatic animals	Vertebrata	Teleostomi	Actinopterygii	Bagridae	Bagrus	bayad	Valcfo	Forskall	Africa	Food	Consumes; plants
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Bagridae	Bagrus	docmac	Valcfo	Forskall	Africa	Food	Consumes fish eggs
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Cyprinidae	Barbus	aureus	Barbel	Cope	Africa, Natal	stocking rivers	Food
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Cyprinidae	Barbus	caudovittatus	Barbel	Boulenger	Africa-Ubanghi	Food	
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Cyprinidae	Barbus	grypus	Barbel	Heckel	Euphrates	Food	
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Cyprinidae	Barbus	holubi	Small-mouthed barbar fish	Steindachner	S.Africa	Propogation-Lakes	Food
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Cyprinidae	Barbus	luteus	Barbel	Heckel	Orontes river	Food	
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Cyprinidae	Barbus	occidentalis	Barbel	Boulenger	Ogun river	Food	
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Cyprinidae	Barbus	paludinosus	Barbel	Peters	Africa	Food	
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Cyprinidae	Barbus	sphaerocyi	Barbel	Gunther	Euphrates river	Food	
Aquatic Animals	Vertebrata	Teleostomi	Actinopterygii	Cyprinidae	Barbus	trimaculatus	Barbel	Peters	Africa	Food	

Appendix Table 4

Aquatic Animals	Vertebrata	Teleostomii	Actinopterygii	Characiniidae	Brycon	henni	Sabaleta	Eigenmann	S. America	Food
Aquatic Animals	Vertebrata	Teleostomii	Actinopterygii	Carangidae	Caranx	delicatissimus	Striped Jack	Doderlein	Coastal Japan	Food
Aquatic Animals	Vertebrata	Teleostomii	Actinopterygii	Cyprinidae	Carassius	auratus	Goldfish	Linnaeus	China, Japan	Aquaria, forage fish
Aquatic Animals	Vertebrata	Teleostomii	Actinopterygii	Cyprinidae	Carassius	auratus gibelio	European goldfish	Bloch	Russian hatcheries	Aquaria, forage fish
Aquatic Animals	Vertebrata	Teleostomii	Actinopterygii	Cyprinidae	Carassius	carassius	Crucian Carp	Linnaeus	Europe, Japan	Water treatment
Aquatic Animals	Vertebrata	Teleostomii	Actinopterygii	Cyprinidae	Catla	catla	Catla	Hamilton	India, Pakistan, Burma	Food
Aquatic Animals	Vertebrata	Teleostomii	Angiosperm	Monocotyledon			Cyperaceae	Eleocharis	planktaginea	Water Chestnut
Angiosperm	Monocotyledon			Cyperaceae	Eleocharis	tuberosa	Water Chestnut	Schulters	Eastern India	tuber eaten
Angiosperm	Dicotyledon			Hydrophyllaceae	Hydrolea	zeylanica		Linnaeus/Vahl	Tropical Asia	Young Leaves eaten
Angiosperm	Dicotyledon			Convolvulaceae	Ipomoea	aquatica	Water Spinach	Forsk.	Tropical Asia	Human consumption
Angiosperm	Monocotyledon			Lemnaceae	Lemna	sp.	Duck Weed		Widely Distributed	Fish culture
Angiosperms	Dicotyledon			Nymphaeaceae	Nelumbium	speciosum	Lotus	Willdenow	Tropical Asia	Food, rhizomes, seeds
Angiosperms	Dicotyledon			Nymphaeaceae	Nymphaea	lotus	White Lotus	Linnaeus	Tropical Africa	root powder- <i>Aluacaster</i>
Angiosperm	Dicotyledon			Nymphaeaceae	Nymphaea	stellata	Indian Blue Lotus	Willdenow	S.E. Asia	Human consumption
Angiosperm	Monocotyledon			Graminae	Oryza	sativa	Rice	Linnaeus	Asia	Human consumption
Angiosperm	Dicotyledon			Onagraraceae	Trapa	bicornis	Water Chestnut	Linnaeus	China	seeds used as food
Angiosperm	Dicotyledon			Onagraraceae	Trapa	bispinosa	Water Chestnut	Roxburgh	India/Kashmir	Raw seeds edible
Angiosperm	Dicotyledon			Onagraraceae	Trapa	natans	Water Chestnut	Linnaeus	Europe	Seeds as food
										Rosaries

Appendix Table 5

Examples of Lifestages and Differential Trophic Function

Organism	Life Stage	ID Term/Taxa	Generic	Linnaean	Food type
Stonefly small species	Nymph (herb)	Two Tailed	Plecoptera	Order	Algae, diatoms, organic debris
Stonefly e.g. Perl	Nymph (cam)	Two Tailed	Plecoptera	Order	Flv larvae, worms, caddis larva
Stonefly	Adult (Neq feeding)	Two Tailed	Plecoptera	Order	Non-eating form
Mavfly	Nymph (spinner) Dun	Three tailed	Ephemeroptera	Order	Algae
Mavfly	Adult	Three Tailed	Ephemeroptera	Order	Non-eating form
Caddis Fly	Larvae (omn/Cam)	Caddis grub	Trichoptera	Order	Smaller Caddis, insect larva, plant material
Caddis Fly	Adult	Caddis Fly	Trichoptera	Order	Neoligidae
Shrimp (Gammarus)	Adult	Pseudo shrimp	Amphipoda	Order	Decomposing Plants/animals
Non biting midges	Eggs	Blood Worms	Chironomidae	Family	Non-feeding eggs anchored to pants by jelly
Non biting midges	Larvae	Blood Worms	Chironomidae	Family	Weak and tend to die before eating
Non biting midges	Pupae	Blood Worms	Chironomidae	Family	Non-feeding form
Non biting midges	Adult	Blood worms	Chironomidae	Family	Most adult forms have weak mouthparts-cannot feed
Alder Fly	Larvae (cam)		Sialidae	Family	Flv larvae, mavfly nymphs, caddis larvae, other inverts
Alder Fly	Adult		Sialidae	Family	Too short lived
Alder Fly	Larvae	'blood' suckers	Osmylus	Family	Chironomid /other aquatic larvae, particularly dipterous
Black Fly	Larva filter feeder	Simuliid	Simulium	Genus	Suspended Solids
Black Fly	Adult	Simulid	Simulium	Genus	Mammals (including man) blood
Mosquito	Larvae	Aedes		Genus	Lives among vegetation
Mosquito	Adult	Aedes	Aedes	genus	Biters of man
Water Spider	Adult		Arachnida	Class	Small Crustacea, insect larva even some small fish
Water Mite	Larva		Hydracarina	Sub-order	Parasitic on diving beetle
Water Mite	Nymph&Adult		Hydracarina	Sub-order	Small Crustaceans, insect larvae worms
Filter Flies	Larvae		Psychoda	Genus	Decaying organic matter
Filter Lies	Adult		Psychoda	Genus	Decaying organic matter
copepods	Adult		Copepoda	Class	Small animals, organic debris, vegetation
Segmented Worm	Adult	Sludge Worm	Tubificidae	Family	Detritus
Flat Worm	Adult	Platyhelminthe	Turbellaria	Class	Small Crustaceans, insect larvae, algae, detritus
Zebra Mussel	Larvae (Veligers)	Bivalvia	Dreissena	Genus	Suspended organic solids
Zebra Mussel	Adult	Bivalvia	Dreissena	Genus	Filter feeding
Carp	Juvenile (carnivore)		Cyprinidae	Family	Small crustaceans
Carp	Adult (omnivore)		Cyprinidae	Family	Plants, insect larvae, small fish
Gravling	Adult (carnivore)		Thymallidae	Family	Benthic inverts
Frog	Tadpole (Herb/det)	Rana	Rana	Genus	Algae, feeds on dead animal material
Frog	Adult	Rana	Rana	Genus	Insects
Newt	Tadpoles (Carnivore)				Small Crustaceans e.g. Daphnia
Newt	Adult	Tailed Amphibians			Tadpoles
Water Boatman	Adults/Nymphs (Cam)	Back Swimmer	Notonectidae	Family	Insects
Lesser Water Boatman	Adult (Herb)	Benthic	Notonectidae	Family	Algae
Water Scorpion	Adult (Cam)		Nepidae	Family	Tadpoles
Water Stick Insects	Adult (Carnivore)		Ranatra		Water Mites
Rainbow Trout	Juvenile (Carnivore)	Salmonidae	Oncorhynchus mykiss	Species	Aquatic insects, Aerial insects
Rainbow Trout	Adult (Carnivore)	Salmonidae	Oncorhynchus mykiss	Species	Planktonic Crustaceans and Fish
Bream	Adult (Carnivore)	Cyprinidae	Abramis brama	Species	Insect Larvae
Perch	Juvenile (cam.)	Percidae	Perca fluviatilis	Species	Small Crustaceans
Perch	Adult (Piscivore.)	Percidae	Perca fluviatilis	Species	Fish
Dragon Fly	Nymph	1-5 years	Anisoptera	Sub-Order	Aquatic Inverts.
Damselfly	Nymph		Zygoptera	Sub-Orders	Small Inverts
Damselfly	Adult		Zygoptera	Sub-Order	
Pike	Adult (Carnivore)	Esocidae	Esox lucius	Species	Most Fish, salmon, trout, frogs even mammals
Pike	Larva (Carnivore)	Esocidae	Esox lucius	Species	Small Invertebrates (Daphnia) and invertebrates
River Limpets	Adult		Anavus fluviatilis	Species	Microscopic Plants
Brock Lamprey	Adult (Parasitic)	Petromyzonidae	Lampetra planeri	Species	Fish Blood
Brock Lamprey	Ammocoetes	Ammocoetes branchialis	Lampetra	Genus	Diatoms
Sun animalcule		Heliozoan	Actinosphaerium	Genus	

Table 7

Reclassification of Biological Data Using the Ecotaxonomy: ‘Hungarian’ Case-Study 1971 (Chapters 8 and 9)

“Limnological investigations of a fish-pond supplied with sewage-water in the vicinity of Lake Balaton I and II”
(Ponyi et. al 1973, 1974).

ID	Year	Phylum	Genus	Species	Ecotaxonomic Development 1	Ecotaxonomic Development 2	Ecotaxonomic Development 3 - Ecotaxa used in analysis
1	1971	Cyanophyta	Anabaena	scheremetievi	1	1	2
2	1971	Cyanophyta	Anabaena	spiroides	1	1	2
3	1971	Cyanophyta	Aphanizomenon	flos-aquae	1	1	2
4	1971	Cyanophyta	Aphanocapsa	delicatissima	1	1	2
5	1971	Cyanophyta	Aphanocapsa	elachista	1	1	2
6	1971	Cyanophyta	Chroococcus	limneticus	1	1	2
7	1971	Cyanophyta	Gomphosphaeria	lacustris	1	1	2
8	1971	Cyanophyta	Lyngbya	limnetica	1	1	2
9	1971	Cyanophyta	Lyngbya	martensiana	1	1	2
10	1971	Cyanophyta	Merismopedia	glauca	1	1	2
11	1971	Cyanophyta	Microcystis	flos-aquae	1	1	2
12	1971	Cyanophyta	Oscillatoria	princeps	1	1	3
13	1971	Cyanophyta	Romeria	elegans	1	1	3
14	1971	Cyanophyta	Spirulina	laxissima	1	1	3
15	1971	Euglenophyta	Euglena	ehrenbergii	1	1	3
16	1971	Euglenophyta	Euglena	klebsii	1	1	2
17	1971	Euglenophyta	Euglena	oxyuris	1	1	2
18	1971	Euglenophyta	Phacus	acuminatus	1	1	2
19	1971	Euglenophyta	Phacus	pseudonordstedtii	1	1	2

Appendix Table 7

20	1971	Euglenophyta	Phacus	pyrum	1	1	2
21	1971	Chrysophyta	Mallomonas	acaroides	1	1	2
22	1971	Chrysophyta	Mallomonas	tonsurata	1	1	2
23	1971	Dinophyta	Peridinium	sp.	1	1	2
24	1971		Botryococcus	braunii	1	1	2
25	1971		Tetrakeritron	tribulus	1	1	2
26	1971		Amphichrysis	compressa	1	1	2
27	1971		Chromulina	sp.	1	1	2
28	1971		Rhizochrysis	limnetica	1	1	2
29	1971	Bacillariophyta/diato	Amphora	ovalis	1	1	2
30	1971	Bacillariophyta/diato	Anomoeneis	spaerophora	1	1	2
31	1971	Bacillariophyta/diato	Cocconeis	diminuta	1	1	2
32	1971	Bacillariophyta/diato	Cocconeis	placentula	1	1	2
33	1971	Bacillariophyta/diato	Cyclotella	meneghiniana	1	1	2
34	1971	Bacillariophyta/diato	Cyclotella	ocellata	1	1	2
35	1971	Bacillariophyta/diato	Cymatopleura	solea	1	1	2
36	1971	Bacillariophyta/diato	Cymatopleura	prostrata	1	1	2
37	1971	Bacillariophyta/diato	Cymbella	cymbiformis	1	1	2
38	1971	Bacillariophyta/diato	Epithemia	sorex	1	1	2
39	1971	Bacillariophyta/diato	Fragilaria	construens	1	1	2
40	1971	Bacillariophyta/diato	Gomphonema	lanceolatum	1	1	2
41	1971	Bacillariophyta/diato	Gyrosigma	kutzingii	1	1	2
42	1971	Bacillariophyta/diato	Melosira	granulata	1	1	2
43	1971	Bacillariophyta/diato	Melosira	granulata var. angustissima	1	1	2
44	1971	Bacillariophyta/diato	Melosira	granulata var. angustissima sp	1	1	2
45	1971	Bacillariophyta/diato	Melosira	varians	1	1	2
46	1971	Bacillariophyta/diato	Navicula	cryptocephala	1	1	2
47	1971	Bacillariophyta/diato	Navicula	hungarica var. capitata	1	1	2
48	1971	Bacillariophyta/diato	Nitzschia	acicularis	1	1	2
49	1971	Bacillariophyta/diato	Nitzschia	sigmoidea	1	1	2
50	1971	Bacillariophyta/diato	Pinnularia	maior	1	1	2

Appendix Table 7

51	1971	Bacillariophyta/diat	Rhizosolenia	longiseta	1	1	1	2
52	1971	Bacillariophyta/diat	Straussonia	alabamiae	1	1	1	2
53	1971	Bacillariophyta/diat	Stephanodiscus	hantzschii	1	1	1	2
54	1971	Bacillariophyta/diat	Suirella	robusta var. splendida	1	1	1	2
55	1971	Bacillariophyta/diat	Suirella	tenera	1	1	1	2
56	1971	Bacillariophyta/diat	Syndera	acus	1	1	1	2
57	1971	Bacillariophyta/diat	Syndera	acus var. angustissima	1	1	1	2
58	1971	Chlorophyta	Chlamydomonas	sp.	1	1	1	2
59	1971	Chlorophyta	Pandorina	morum	1	1	1	2
60	1971	Chlorophyta	Actinastrum	hantzschii	1	1	1	2
61	1971	Chlorophyta	Ankistrodesmus	falcatus	1	1	1	2
62	1971	Chlorophyta	Ankistrodesmus	falcatus var. acicularis	1	1	1	2
63	1971	Chlorophyta	Ankistrodesmus	falcatus var. mirabile	1	1	1	2
64	1971	Chlorophyta	Ankistrodesmus	lacustris	1	1	1	2
65	1971	Chlorophyta	Ankistrodesmus	longissimus	1	1	1	2
66	1971	Chlorophyta	Chodatella	balatonica	1	1	1	2
67	1971	Chlorophyta	Chodatella	ciliata	1	1	1	2
68	1971	Chlorophyta	Chodatella	quadrifida	1	1	1	2
69	1971	Chlorophyta	Coelastrum	microporum	1	1	1	2
70	1971	Chlorophyta	Coelastrum	spaeicum	1	1	1	2
71	1971	Chlorophyta	Crucigenia	tetrapedia	1	1	1	2
72	1971	Chlorophyta	Dictyosphaerium	pulchellum	1	1	1	2
73	1971	Chlorophyta	Golenkinia	radiata	1	1	1	2
74	1971	Chlorophyta	Micractinium	pusillum	1	1	1	2
75	1971	Chlorophyta	Oocystis	solitaria	1	1	1	2
76	1971	Chlorophyta	Pediastrum	boryanum	1	1	1	2
77	1971	Chlorophyta	Pediastrum	boryanum var. granulatum	1	1	1	2
78	1971	Chlorophyta	Pediastrum	simplex	1	1	1	2
79	1971	Chlorophyta	Pediastrum	tetras	1	1	1	2
80	1971	Chlorophyta	Scenedesmus	acuminatus	1	1	1	2
81	1971	Chlorophyta	Scenedesmus	carinatus var. polycostatus	1	1	1	2

Appendix Table 7

82	1971	Chlorophyta	Scenedesmus	denticulatus	1	1	2
83	1971	Chlorophyta	Scenedesmus	dispar	1	1	2
84	1971	Chlorophyta	Scenedesmus	ecornis	1	1	2
85	1971	Chlorophyta	Scenedesmus	ecornis var. disciformis	1	1	2
86	1971	Chlorophyta	Scenedesmus	ellipsoideus	1	1	2
87	1971	Chlorophyta	Scenedesmus	intermedius	1	1	2
88	1971	Chlorophyta	Scenedesmus	quadricauda	1	1	2
89	1971	Chlorophyta	Scenedesmus	quadricauda var. biomata	1	1	2
90	1971	Chlorophyta	Scenedesmus	quadricauda var. biomata gig.	1	1	2
91	1971	Chlorophyta	Scenedesmus	quadricauda var. longispina	1	1	2
92	1971	Chlorophyta	Scenedesmus	pannonicus	1	1	2
93	1971	Chlorophyta	Scenedesmus	spinosus	1	1	2
94	1971	Chlorophyta	Selenastrum	gracile	1	1	2
95	1971	Chlorophyta	Tetraedron	caudatum var. incisum	1	1	2
96	1971	Chlorophyta	Tetraedron	cruciatum	1	1	2
97	1971	Chlorophyta	Tetraedron	hastatum var. palatinum	1	1	2
98	1971	Chlorophyta	Tetraedron	minimum	1	1	2
99	1971	Chlorophyta	Tetraedron	muticum	1	1	2
100	1971	Chlorophyta	Tetraedron	proteiforme	1	1	2
101	1971	Chlorophyta	Tetraedron	regulare	1	1	2
102	1971	Chlorophyta	Tetrastrum	heteracanthum	1	1	2
103	1971	Chlorophyta	Tetrastrum	staurogeniaeforme	1	1	2
104	1971	Chlorophyta	Treubaria	triappendiculata	1	1	2
105	1971	Chlorophyta	Closterium	acerosum var. elongatum	1	1	2
106	1971	Chlorophyta	Cosmarium	sp. (I)	1	1	2
107	1971	Chlorophyta	Cosmarium	sp. (II)	1	1	2
108	1971	Chlorophyta	Cosmarium	sp. (III)	1	1	2
109	1971	Chlorophyta	Staurastrum	furcigerum	1	1	2
110	1971	Chlorophyta	Staurastrum	gracile	1	1	2
111	1971	Chlorophyta	Staurastrum	paradoxum	1	1	2
112	1971	Chlorophyta	Spirogyra	sp. (I)	1	1	2

Appendix Table 7

113	1971	Chlorophyta	Spirogyra	sp. (II)	1	1	2
114	1971	Mycophyta	Planktomyces	bekefi	1	1	2
115	1971	Rotifera	Asplanchna	amphora	5	5	18
116	1971	Rotifera	Asplanchna	brightwelli	5	5	18
117	1971	Rotifera	Asplanchna	girodi	5	5	18
118	1971	Rotifera	Asplanchna	sieboldi	5	5	18
119	1971	Rotifera	Anuraeopsis	fissa	2	2	
120	1971	Rotifera	Bdelloidea	sp.	2	4	14
121	1971	Rotifera	Brachionus	angularis	2	5	18
122	1971	Rotifera	Brachionus	budapestinensis	2	5	18
123	1971	Rotifera	Brachionus	calyciflorus calyciflorus	2	5	18
124	1971	Rotifera	Brachionus	calyciflorus anuraeiformis	2	5	18
125	1971	Rotifera	Brachionus	calyciflorus amphiceros	2	5	18
126	1971	Rotifera	Brachionus	calyciflorus dorcas	2	5	18
127	1971	Rotifera	Brachionus	calyciflorus dorcas spinosa	2	5	18
128	1971	Rotifera	Brachionus	diversicornis diversicornis	2	5	18
129	1971	Rotifera	Brachionus	leydigii	2	5	18
130	1971	Rotifera	Brachionus	plicatilis	2	5	18
131	1971	Rotifera	Brachionus	rubens	2	5	19
132	1971	Rotifera	Brachionus	quadridentatus	2	5	18
133	1971	Rotifera	Brachionus	quadridentatus ancylognathus	2	5	18
134	1971	Rotifera	Brachionus	quadridentatus bravispinus	2	5	18
135	1971	Rotifera	Brachionus	Quadridentatus cluniorbicular	2	5	18
136	1971	Rotifera	Brachionus	quadridentatus rectangularis	2	5	18
137	1971	Rotifera	Brachionus	quadridentatus rhenanus	2	5	18
138	1971	Rotifera	Cephalodella	gibba	2	4	14
139	1971	Rotifera	Chromogaster	ovalis			
140	1971	Rotifera	Colurella	adriatica	2	4	14
141	1971	Rotifera	Colurella	colurus	2	4	14
142	1971	Rotifera	Colurella	obtusa	2	4	14
143	1971	Rotifera	Colurella	obtusa aperta	2	4	14

Appendix Table 7

144	1971	Rotifera	Collotheca	sp.		2	4	13
145	1971	Rotifera	Conochilus	unicornis				
146	1971	Rotifera	Euchlanis	deflexa		2	6	22
147	1971	Rotifera	Euchlanis	dilatata lucksiana		2	6	22
148	1971	Rotifera	Epiphanes	macrourus		2	5	18
149	1971	Rotifera	Filinia	longiseta		2	4	14
150	1971	Rotifera	Keratella	cochlearis		2	5	18
151	1971	Rotifera	Keratella	cochlearis macracantha		2	5	18
152	1971	Rotifera	Keratella	cochlearis macracantha		2	5	18
153	1971	Rotifera	Keratella	tecta		2	5	18
154	1971	Rotifera	Keratella	quadrata		2	5	18
155	1971	Rotifera	Lecane	bullae		2	5	18
156	1971	Rotifera	Lecane	closteroerca		2	4	14
157	1971	Rotifera	Lecane	hamata		2	4	14
158	1971	Rotifera	Lecane	lunaris		2	4	14
159	1971	Rotifera	Lecane	stenocosi		2	4	14
160	1971	Rotifera	Lepadella	ovalis		2	4	14
161	1971	Rotifera	Lepadella	patella		2	4	14
162	1971	Rotifera	Lophocaris	salpina		2	4	14
163	1971	Rotifera	Monommata	longiseta		2	6	22
164	1971	Rotifera	Mytilina	mucronata		2	4	14
165	1971	Rotifera	Pedalia	mira		2	4	14
166	1971	Rotifera	Platylas	quadricornis		2	5	18
167	1971	Rotifera	Philodina	sp.		2	5	18
168	1971	Rotifera	Polyarthra	vulgaris		2	5	18
169	1971	Rotifera	Pompholyx	sulcata		2	4	14
170	1971	Rotifera	Proalides	tentaculatus		2	4	14
171	1971	Rotifera	Proales	sp.		2	4	14
172	1971	Rotifera	Rotatoria	sp.		2	5	20
173	1971	Rotifera	Trichocerca	dixon-nuttalli		2	6	22
174	1971	Rotifera	Trichocerca	pusilla		2	6	22

Appendix Table 7

175	1971	Rotifera	Trichocerca	stylata	2	4	14
176	1971	Rotifera	Trichotria	pocillum	2	4	14
177	1971	Crustacea	Daphnia	hyalina var. lacustris	2	5	18
178	1971	Crustacea	Simocephalus	vetulus	2	5	18
179	1971	Crustacea	Ceriodaphnia	pulchella	2	5	18
180	1971	Crustacea	Moina	rectirostris	2	5	18
181	1971	Crustacea	Scapholeberis	kingi	2	5	18
182	1971	Crustacea	Macrothrix	laticornis	2	4	14
183	1971	Crustacea	Ilyocryptus	sordidus			
184	1971	Crustacea	Ilyocryptus	agilis			
185	1971	Crustacea	Leydigia	leydigii			
186	1971	Crustacea	Chydorus	sphaericus	2	5	18
187	1971	Crustacea	Pleuroxus	trigonellus			
188	1971	Crustacea	Alona	affinis			
189	1971	Crustacea	Alona	quadrangularis			
190	1971	Crustacea	Alona	guttata			
191	1971	Crustacea	Alona	rectangula rectangula			
192	1971	Crustacea	Bosmina	longirostris f. cornuta	2	6	22
193	1971	Crustacea	Bosmina	longirostris f. curvirostris	2	6	22
194	1971	Crustacea	Leydigia	acanthocercoides			
195	1971	Crustacea	Macrocylops	albidus	2	6	22
196	1971	Crustacea	Paracyclops	fimbriatus	2	6	22
197	1971	Crustacea	Cyclops	vicinus	2	6	22
198	1971	Crustacea	Acanthocyclops	vernalis	2	6	22
199	1971	Crustacea	Thermocyclops	crassus	2	6	22
200	1971	Crustacea	Cyclops	sp.	2	6	22
201	1971	Crustacea	Cyclops	naupliua	2	6	22
202	1971	Crustacea	Lymnocythere	inopinata	2		
203	1971	Crustacea	Cyclopyris	laevis			
204	1971	Crustacea	Cypridopsis	vidua			
205	1971	Crustacea	Cyclopyris	ovum			

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206	1971	Crustacea	Cypria	opthalmica			
207	1971	Crustacea	Darwinula	stevensoni		6	22
208	1971	Crustacea	Eucyclops	serrulatus			
209	1971	Crustacea	Nitocra	hibernica		4	16
210	1971	Crustacea	Tubifex	tubifex	2	4	15
211	1971	Annelida			2		
212	1971	Nematoda			3	7	27
213	1971	Pisces	Tinca	tinca	3	7	27
214	1971	Pisces	Cyprinus	carpio	3		
215	1971	Pisces	Silurus	glanis	3	8	30
216	1971	Pisces	Ctenopharyngodo	idella	2	6	22
217	1971	Pisces	Stizostedion	lucio-perca	3	8	30
218	1971	Pisces	Parabramis	pekinensis	3	7	26
219	1971	Pisces	Hypophthalmichthys	nobilis	3	8	30
220	1971	Pisces	Hypophthalmichthys	molitrix	2	5	18
221	1971	Pisces	Esox	lucius	3	8	30
222	1971	Pisces	Carassius	carassius	3	7	26
223	1971	Pisces	Carassius	carassius gibelio	3	7	27

Table 8

Reclassification of Biological Data Using the Ecotaxonomy: 'Hungarian' Case-Study 1972 (Chapters 8 and 9)
"Limnological investigations of a fish-pond supplied with sewage-water in the vicinity of Lake Balaton I and II"
 (Ponyi et. al 1973, 1974).

Limnological Study-1972

ID	Year	Phylum	Genus	Species	Ecotaxonomic Development 1	Ecotaxonomic Development 2	Ecotaxonomic Development 3	Ecotaxonomic Development used in analysis
1	1972	Cyanophyta	Anabaena	flos-aquae	1	1	2	2
2	1972	Cyanophyta	Anabaena	scheremetievi	1	1	2	2
3	1972	Cyanophyta	Anabaena	spiroideis	1	1	2	2
4	1972	Cyanophyta	Aphanizomenon	flos-aquae	1	1	2	2
5	1972	Cyanophyta	Aphanizomenon	ovalosporum	1	1	2	2
6	1972	Cyanophyta	Aphanocapsa	delicatissima	1	1	2	2
7	1972	Cyanophyta	Chroococcus	limneticus	1	1	2	2
8	1972	Cyanophyta	Chroococcus	minimus	1	1	2	2
9	1972	Cyanophyta	Chroococcus	minutus	1	1	2	2
10	1972	Cyanophyta	Chroococcus	turgidus	1	1	2	2
11	1972	Cyanophyta	Coelosphaerium	kutzingianum				
12	1972	Cyanophyta	Gomphosphaerium	lacustria	1	1	2	2
13	1972	Cyanophyta	Lyngbya	limnetica	1	1	2	2
14	1972	Cyanophyta	Merismopedia	glaucia	1	1	2	2
15	1972	Cyanophyta	Microcystis	flos-aquae	1	1	2	2
16	1972	Cyanophyta	Microcystis	pulverea	1	1	2	2
17	1972	Cyanophyta	Oscillatoria	planctonica	1	1	3	3
18	1972	Cyanophyta	Oscillatoria	tenuis	1	1	3	3
19	1972	Cyanophyta	Spirulina	laxissima	1	1	3	3
20	1972	Cyanophyta	Merismopedia	tenuissima	1	1	2	2
21	1972	Euglenophyta	Euglena	acus	1	1	2	2
22	1972	Euglenophyta	Euglena	ehrenbergii	1	1	3	3

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23	1972	Euglenophyta	Euglena	gaumei	1	1	2
24	1972	Euglenophyta	Euglena	limnophila var. minor	1	1	2
25	1972	Euglenophyta	Euglena	oxyuris	1	1	2
26	1972	Euglenophyta	Phacus	acuminatus	1	1	2
27	1972	Euglenophyta	Phacus	longicauda	1	1	2
28	1972	Euglenophyta	Trachelomonas	scabra	1	1	2
29	1972	Euglenophyta	Trachelomonas	volvocina	1	1	2
30	1972	Cryptophyta	Cryptomonas	erosa	1	1	2
31	1972	Cryptophyta	Cryptomonas	ovata	1	1	2
32	1972	Dinophyta	Peridinium	inconspicuum	1	1	2
33	1972	Dinophyta	Peridinium	latum	1	1	2
34	1972	Chrysophyta	Planktonema	lauterborni	1	1	2
35	1972	Chrysophyta	Tetrakentron	trilobulus	1	1	2
36	1972	Euglenophyta	Phacus	trypanon	1	1	2
37	1972	Chrysophyta	Amphichrysis	compressa	1	1	2
38	1972	Chrysophyta	Chromulina	sp.	1	1	2
39	1972	Chrysophyta	Chrysococcus	rufescens	1	1	2
40	1972	Chrysophyta	Mallomonas	elongata	1	1	2
41	1972	Chrysophyta	Mallomonas	tonsurata	1	1	2
42	1972	Chrysophyta	Mallomonas	acaroides	1	1	2
43	1972	Chrysophyta	Rhizochrysis	limnetica	1	1	2
44	1972	Chrysophyta	Salpingoeca	frequentissima	1	1	2
45	1972	Bacillariophyta/diatom	Amphora	ovalis	1	1	2
46	1972	Bacillariophyta/diatom	Attheya	zachvatyi	1	1	2
47	1972	Bacillariophyta/diatom	Cocconeis	placenticula	1	1	2
48	1972	Bacillariophyta/diatom	Cyclotella	bodanica	1	1	2
49	1972	Bacillariophyta/diatom	Cyclotella	comta	1	1	2
50	1972	Bacillariophyta/diatom	Cyclotella	glomerata	1	1	2
51	1972	Bacillariophyta/diatom	Cyclotella	meneghiniana	1	1	2
52	1972	Bacillariophyta/diatom	Cyclotella	ocellata	1	1	2
53	1972	Bacillariophyta/diatom	Fragilaria	construens	1	1	2
54	1972	Bacillariophyta/diatom	Gomphonema	olivaceum	1	1	2

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55	1972	Bacillariophyta/diatom	Melosira	granulata	1	1	1	2
56	1972	Bacillariophyta/diatom	Melosira	granulata var. angustis.	1	1	1	2
57	1972	Bacillariophyta/diatom	Melosira	granulata var. angustis.	1	1	1	2
58	1972	Bacillariophyta/diatom	Melosira	varians	1	1	1	2
59	1972	Bacillariophyta/diatom	Navicula	cryptocephala	1	1	1	2
60	1972	Bacillariophyta/diatom	Navicula	gracilis	1	1	1	2
61	1972	Bacillariophyta/diatom	Navicula	hungarica var. capitata	1	1	1	2
62	1972	Bacillariophyta/diatom	Navicula	radiosa	1	1	1	2
63	1972	Bacillariophyta/diatom	Nitzschia	acicularis	1	1	1	2
64	1972	Bacillariophyta/diatom	Nitzschia	amphibia	1	1	1	2
65	1972	Bacillariophyta/diatom	Nitzschia	hungarica	1	1	1	2
66	1972	Bacillariophyta/diatom	Nitzschia	palea	1	1	1	2
67	1972	Bacillariophyta/diatom	Nitzschia	subrostrata	1	1	1	2
68	1972	Bacillariophyta/diatom	Pinnularia	maior	1	1	1	2
69	1972	Bacillariophyta/diatom	Stauroneis	alabarnae	1	1	1	2
70	1972	Bacillariophyta/diatom	Stephanodiscus	hantzschii	1	1	1	2
71	1972	Bacillariophyta/diatom	Synedra	acus var. angustissima	1	1	1	2
72	1972	Chlorophyta	Actinastrum	hantzschii	1	1	1	2
73	1972	Chlorophyta	Actinastrum	hantzschii var. fluviale	1	1	1	2
74	1972	Chlorophyta	Ankistrodesmus	falcatus	1	1	1	2
75	1972	Chlorophyta	Ankistrodesmus	falcatus var. acicularis	1	1	1	2
76	1972	Chlorophyta	Ankistrodesmus	falcatus var. mirabile	1	1	1	2
77	1972	Chlorophyta	Ankistrodesmus	falcatus var. spirilliformis	1	1	1	2
78	1972	Chlorophyta	Chlamydomonas	braunii	1	1	1	2
79	1972	Chlorophyta	Chlamydomonas	clangeardii	1	1	1	2
80	1972	Chlorophyta	Chodatella	balatonica	1	1	1	2
81	1972	Chlorophyta	Chodatella	ciliata	1	1	1	2
82	1972	Chlorophyta	Closterium	acerosum	1	1	1	2
83	1972	Chlorophyta	Closterium	aciculare	1	1	1	2
84	1972	Chlorophyta	Coelastrum	reticulatum	1	1	1	2
85	1972	Chlorophyta	Coelastrum	cambricum var. intermed.	1	1	1	2
86	1972	Chlorophyta	Coelastrum	microporum	1	1	1	2

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87	1972	Chlorophyta	Cosmarium	bicardia	1	1	2
88	1972	Chlorophyta	Cosmarium	impressulum	1	1	2
89	1972	Chlorophyta	Crucigenia	apiculata	1	1	2
90	1972	Chlorophyta	Crucigenia	quadrata	1	1	2
91	1972	Chlorophyta	Crucigenia	tetrapedia	1	1	2
92	1972	Chlorophyta	Dictyosphaerium	pulchellum	1	1	2
93	1972	Chlorophyta	Elakatothrix	lacustris	1	1	2
94	1972	Chlorophyta	Golenkinia	radiata	1	1	2
95	1972	Chlorophyta	Kirchneriella	contorta	1	1	2
96	1972	Chlorophyta	Micractinium	pusillum	1	1	2
97	1972	Chlorophyta	Oocystis	crassa var. marssonii	1	1	2
98	1972	Chlorophyta	Oocystis	lacustris	1	1	2
99	1972	Chlorophyta	Oocystis	parva	1	1	2
100	1972	Chlorophyta	Pediastrum	boryanum	1	1	2
101	1972	Chlorophyta	Pediastrum	duplex	1	1	2
102	1972	Chlorophyta	Pediastrum	simplex	1	1	2
103	1972	Chlorophyta	Pediastrum	sturmii	1	1	2
104	1972	Chlorophyta	Pediastrum	tetras	1	1	2
105	1972	Chlorophyta	Kirchneriella	obesa	1	1	2
106	1972	Chlorophyta	phacotus	lenticularis	1	1	2
107	1972	Chlorophyta	Scenedesmus	acuminatus	1	1	2
108	1972	Chlorophyta	Scenedesmus	acuminatus f. tortuosus	1	1	2
109	1972	Chlorophyta	Scenedesmus	acuminatus var. elongatus	1	1	2
110	1972	Chlorophyta	Scenedesmus	arcuatus	1	1	2
111	1972	Chlorophyta	Scenedesmus	balatonicus	1	1	2
112	1972	Chlorophyta	Scenedesmus	carinatus var. polycosatus	1	1	2
113	1972	Chlorophyta	Scenedesmus	dispar	1	1	2
114	1972	Chlorophyta	Scenedesmus	ecornis	1	1	2
115	1972	Chlorophyta	Scenedesmus	intermedius	1	1	2
116	1972	Chlorophyta	Scenedesmus	popoliensis	1	1	2
117	1972	Chlorophyta	Scenedesmus	pannonicus	1	1	2
118	1972	Chlorophyta	Scenedesmus	protuberans	1	1	2

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119	1972	Chlorophyta	Scenedesmus	quadricauda	1	1	2
120	1972	Chlorophyta	Scenedesmus	quadricauda var. biornata	1	1	2
121	1972	Chlorophyta	Scenedesmus	quadricauda var. biornata	1	1	2
122	1972	Chlorophyta	Scenedesmus	quadricauda var. longispi	1	1	2
123	1972	Chlorophyta	Scenedesmus	quadricauda var. maximus	1	1	2
124	1972	Chlorophyta	Scenedesmus	spinosus	1	1	2
125	1972	Chlorophyta	Schroederia	setigera	1	1	2
126	1972	Chlorophyta	Seleniastrum	gracile	1	1	2
127	1972	Chlorophyta	Staurastrum	paradoxum	1	1	2
128	1972	Chlorophyta	Stylosphaeridium	stipitatum	1	1	2
129	1972	Chlorophyta	Tetraedron	caudatum var. incisum	1	1	2
130	1972	Chlorophyta	Tetraedron	hastatum	1	1	2
131	1972	Chlorophyta	Tetraedron	minimum	1	1	2
132	1972	Chlorophyta	Tetraedron	regulare	1	1	2
133	1972	Chlorophyta	Tetrastrum	staurogeniaeforme	1	1	2
134	1972	Chlorophyta	Tetrastrum	elegans	1	1	2
135	1972	Chlorophyta	Treubaria	triappendiculata	1	1	2
136	1972	Mycophyta	Planktomyces	bekefi	1	1	2
137	1972	Rotifera	Asplanchna	piriodonta	2	5	18
138	1972	Rotifera	Asplanchna	girodi	2	5	18
139	1972	Rotifera	Asplanchna	sieboldi	2	5	18
140	1972	Rotifera	Anuraeopsis	flissa	2	5	18
141	1972	Rotifera	Bdelloidea	sp.	2	5	18
142	1972	Rotifera	Brachionus	angularis	2	5	18
143	1972	Rotifera	Brachionus	angularis bidens	2	5	18
144	1972	Rotifera	Brachionus	budapestinensis	2	5	18
145	1972	Rotifera	Brachionus	calyciflorus calyciflorus	2	5	18
146	1972	Rotifera	Brachionus	calyciflorus anuraeiformis	2	5	18
147	1972	Rotifera	Brachionus	calyciflorus amphiceros	2	5	18
148	1972	Rotifera	Brachionus	calyciflorus diercas	2	5	18
149	1972	Rotifera	Brachionus	calyciflorus spinosus	2	5	18
150	1972	Rotifera	Brachionus	diversicornis diversicorn.	2	5	18

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151	1972	Rotifera	Brachionus	falcatus	2	5	18
152	1972	Rotifera	Brachionus	leydigii leydigii	2	5	18
153	1972	Rotifera	Brachionus	leydigii rotundus	2	5	18
154	1972	Rotifera	Brachionus	leydigii quadratus	2	5	18
155	1972	Rotifera	Brachionus	urceolaris	2	5	18
156	1972	Rotifera	Brachionus	rubens	2	5	19
157	1972	Rotifera	Brachionus	quadridentatus quantatus	2	5	18
158	1972	Rotifera	Brachionus	quadridentatus brevispius	2	5	18
159	1972	Rotifera	Brachionus	quadridentatus cluniorbis	2	5	18
160	1972	Rotifera	Chromogaster	ovalis			
161	1972	Rotifera	Colurella	colurus	2	4	14
162	1972	Rotifera	Colurella	obtusa	2	4	14
163	1972	Rotifera	Colurella	uncinata	2	4	14
164	1972	Rotifera	Colurella	paludosa	2	4	14
165	1972	Rotifera	Dissotrocha	sp.			
166	1972	Rotifera	Euchlanis	parva	2	6	22
167	1972	Rotifera	Euchlanis	dilatata lucksiana	2	6	22
168	1972	Rotifera	Ephiphanes	macrourus	2	5	18
169	1972	Rotifera	Filinia	longiseta	2	4	14
170	1972	Rotifera	Keratella	cochlearis	2	5	18
171	1972	Rotifera	Keratella	cochlearis macracantha	2	5	18
172	1972	Rotifera	Keratella	tecta	2	5	18
173	1972	Rotifera	Keratella	cochlearis hispida ecaudata	2	5	18
174	1972	Rotifera	Keratella	quadrata	2	5	18
175	1972	Rotifera	Lecane	bullata	2	5	18
176	1972	Rotifera	Lecane	closteroerca	2	4	14
177	1972	Rotifera	Lecane	hamata	2	4	14
178	1972	Rotifera	Ascomorpha	saltans			
179	1972	Rotifera	Cephalodella	ventripes	2	4	14
180	1972	Rotifera	Colurella	uncinata uncinata	2	4	14
181	1972	Rotifera	Dicranophorus	forcipatus			
182	1972	Rotifera	Enicetruncum	sp.			

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183	1972	Rotifera	Itura	aurita				
184	1972	Rotifera	Itura	myersi				
185	1972	Rotifera	Lecane	clara	2	4	14	
186	1972	Rotifera	Lecane	quadridentata	2	4	14	
187	1972	Rotifera	Lepadella	patella	2	4	14	
188	1972	Rotifera	Lophocharis	oxystemon	2	4	14	
189	1972	Rotifera	Mytilina	ventralis	2	4	14	
190	1972	Rotifera	Polyarthra	vulgaris	2	5	18	
191	1972	Rotifera	Trichocerca	pusilla	2	6	22	
192	1972	Rotifera	Trichocerca	fligris	2	5	22	
193	1972	Rotifera	Trichocerca	elongata	2	5	22	
194	1972	Crustacea	Daphnia	hyalina	2	5	18	
195	1972	Crustacea	Ceriodaphnia	pulchella	2	5	18	
196	1972	Crustacea	Moina	rectirostris	2	5	18	
197	1972	Crustacea	Chydorus	sphaericus	2	5	18	
198	1972	Crustacea	Pleuroxus	trigoneus				
199	1972	Crustacea	Bosmina	longirostris f. cornuta	2	6	22	
200	1972	Crustacea	Bosmina	longirostris f. curvirostris	2	6	22	
201	1972	Crustacea	Ostracoda	sp. (larvae)	2	4	14	
202	1972	Crustacea	Cyclops	vicinus	2	6	22	
203	1972	Crustacea	Acanthocyclops	vernalis				
204	1972	Crustacea	Cyclops	(copepodit)	2	4	14	
205	1972	Crustacea	Cyclops	(nauplius)	2	6	22	
206	1972	Crustacea	Simocephalus	vetulus	2	5	18	
207	1972	Crustacea	Macrocyclus	albidus	2	6	22	
208	1972	Crustacea	Eucyclops	serrulatus	2	6	22	
209	1972	Insecta	Chironomus	(larvae)	2	4	16	
210	1972	Crustacea	Ilyocryptus	sordidus				
211	1972	Crustacea	Leydigia	acanthocercoides				
212	1972	Crustacea	Alona	quadrangularis				
213	1972	Crustacea	Alona	rectangula				
214	1972	Crustacea	Alona	sp. (juvenile)				

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215	1972	Crustacea	Cyclocypris	ovum			
216	1972	Crustacea	Cypria	sp.			
217	1972	Crustacea	Limnocythere	linopinatia			
218	1972	Crustacea	Cyclops	vicinus	2	6	22
219	1972	Pisces	Cyprinus	carpio	3	7	27
220	1972	Pisces	Hypophthalmichthys	molitrix	2	5	18
221	1972	Pisces	Hypophthalmichthys	mobilis	3	8	30
222	1972	Pisces	Tinca	tinca	3	7	27
223	1972	Pisces	Carassius	carassius	3	7	26
224	1972	Pisces	Carassius	auratus gibelio	3	7	26
225	1972	Insecta	Chironomus	ex. Gr. Plumosus	2	4	16

Table 9

Reclassification of Biological Data Using the Ecotaxonomy: The ‘Little Rock’ Case-Study(Chapters 8 and 9)

“Artifacts or Attributes ? Effects of Resolution on the Little Rock Lake Food Web. ” (Neo D Martinez 1991)

ID	Group	Genus	Species	Ecotaxonomic Development 1	Ecotaxonomic Development 2	Ecotaxonomic Devbvelopment 3 Ecotaxa used in analysis
1	Filamentous algae	Bambusina			1	1
2	Filamentous algae	Batrachospermium			1	2
3	Filamentous algae	Biriaclearia			1	2
4	Filamentous algae	Bulbochaete			1	2
5	Filamentous algae	Desmidiium			1	2
6	Filamentous algae	Gerrinella			1	2
7	Filamentous algae	Groenbladia			1	2
8	Filamentous algae	Hapalosiphon			1	2
9	Filamentous algae	Hyalotheca			1	2
10	Filamentous algae	Lynghya			1	2
11	Filamentous algae	Microchaete			1	2
12	Filamentous algae	Microcoleus			1	2
13	Filamentous algae	Mougeotia			1	2
14	Filamentous algae	Oedogonium			1	2
15	Filamentous algae	Oscillator			1	3
16	Filamentous algae	Plectonema			1	2
17	Filamentous algae	Radlofilum			1	2
18	Filamentous algae	Rhizoclonium			1	2

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19	Filamentous algae	Schizothrix	1	1	2
20	Filamentous algae	Scytonema	1	1	2
21	Filamentous algae	Sphaerocysta	1	1	2
22	Filamentous algae	Spirogyra	1	1	2
23	Filamentous algae	Tribonema	1	1	2
24	Filamentous algae	Zygnema	1	1	2
25	Filamentous algae	Phormidium	1	1	2
26	Cyanobacteria	Chroococcus	1	1	2
27	Cyanobacteria	Gloeotheca	1	1	2
28	Cyanobacteria	Merismopedia	1	1	2
29	Cyanobacteria	Aphanocapsa	1	1	2
30	Cyanobacteria	Gomphosphaeria	1	1	2
31	Cyanobacteria	Coelosphaerium	1	1	2
32	Cyanobacteria	Rhabdoderma	1	1	2
33	Cyanobacteria	Aphanothece	1	1	2
34	Cyanobacteria	Anabaena	1	1	3
35	Chlorophyta	Arthrodesmus	1	1	2
36	Chlorophyta	Cosmarium	1	1	2
37	Chlorophyta	Crucigenia	1	1	2
38	Chlorophyta	Euastrum	1	1	2
39	Chlorophyta	Oocystis	1	1	2
40	Chlorophyta	Pediastrum	1	1	2
41	Chlorophyta	Quadrigula	1	1	2
42	Chlorophyta	Schroederia	1	1	2
43	Chlorophyta	Spondylosium	1	1	2
44	Chlorophyta	Staurastrum	1	1	2
45	Chlorophyta	Tetradron	1	1	2
46	Chlorophyta	Ankistrodesmus	1	1	2
47	Chlorophyta	Xanthidium	1	1	2
48	Chlorophyta	Elakothrix	1	1	2

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49	Chlorophyta	Scenedesmus			1	2
50	Euglenophyta	Phacus			1	2
51	Euglenophyta	Trachelomonas			1	2
52	Cryptophyta	Chroomonas			1	2
53	Cryptophyta	Cryptomonas			1	2
54	Chrysophyceae	Asterionella			1	2
55	Chrysophyceae	Dinobryon			1	2
56	Chrysophyceae	Mallomonas			1	2
57	Chrysophyceae	Synedra			1	2
58	Chrysophyceae	Synura			1	2
59	Chrysophyceae	Tabellaria			1	2
60	Pelagic rotifers	Corrichilus	unicornis		8	29
61	Pelagic rotifers	Corrichiloides			8	30
62	Pelagic rotifers	Kellicottia	longispina		8	30
63	Pelagic rotifers	Kellicottia	bostoniensis		8	30
64	Pelagic rotifers	Keratella	cochlearis		8	30
65	Pelagic rotifers	Keratella	taurocephala		8	30
66	Pelagic rotifers	Keratella	crassa		8	30
67	Pelagic rotifers	Keratella	hiemalis		8	30
68	Pelagic rotifers	Polyarthra	remata		8	30
69	Pelagic rotifers	Polyarthra	vulgaris		8	30
70	Pelagic rotifers	Trichocerca	cylindrica		8	30
71	Pelagic rotifers	Asplanchna			8	30
72	Pelagic rotifers	Gastropus			8	30
73	Pelagic rotifers	Synchaeta			8	30
74	Juvenile pelagic zoopl	Nauplii			8	30
75	Juvenile pelagic zoopl	Calanoid	copepodids		8	30
76	Juvenile pelagic zoopl	Cyclopoid	copepodid		8	30
77	Pelagic cladocera	Bosmina	longirostris		8	30
78	Pelagic cladocera	Eubosmina			8	30

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79	Pelagic cladocera	Daphnia	galeata mendotae	3	8	30
80	Pelagic cladocera	Daphnia	parvula	3	8	30
81	Pelagic cladocera	Diaphanosoma	birgei	3	8	30
82	Pelagic cladocera	Holopedium	gibberum	3	8	30
83	Pelagic cladocera	Leptodora	kindtii	3	8	30
84	Pelagic cladocera	Polyphemus	pediculus	3	8	30
85	Pelagic copepods	Diaptomus	minutus	3	8	30
86	Pelagic copepods	Diatocyclops	thomasi	3	8	30
87	Pelagic copepods	Mesocyclops	edax	3	8	30
88	Pelagic copepods	Tropocyclops	prasinus	3	8	30
89	Pelagic copepods	Epischura	lacustris	3	8	30
90	Benthic cladocera	Alona	affinis	2	4	14
91	Benthic cladocera	Alona	quadrangularis	2	4	14
92	Benthic cladocera	Alona	rustica	2	4	14
93	Benthic cladocera	Alona	intermedia	2	4	14
94	Benthic cladocera	Alonella	excisa	2	4	14
95	Benthic cladocera	Disparalona	acutirostris	2	4	14
96	Benthic cladocera	Chydorus	sp1	2	4	14
97	Benthic cladocera	Chydorus	sp2	2	4	14
98	Benthic cladocera	Acantholeberis	curvirostris	2	4	14
99	Benthic cladocera	Ophryoxus	gracilis	2	4	14
100	Benthic cladocera	Scapholeberis	kingi	2	4	14
101	Benthic cladocera	Sida	crystallina	2	4	13
102	Benthic copepods	Macrocylops	serrulatus	3	7	26
103	Benthic copepods	Eucyclops		3	7	26
104	Benthic copepods	Acanthocyclops		3	7	26
105	Benthic copepods	Microcyclops	rubellus	3	7	26
106	Benthic copepods	Harpacticoid	copepods	2	4	14
107	Benthic copepods	Harpacticoid	copepods	2	4	14
108	Hemiptera	Gerris		3	9	34

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109	Coleoptera	Hydroporus				7	26
110	Coleoptera	Gyrinus				7	26
111	Ephemeroptera	Leptophlebia				4	14
112	Ephemeroptera	Caenis				4	14
113	Trichoptera	Oecetis				7	26
114	Trichoptera	Mystacides				4	14
115	Trichoptera	Limnephilus				7	26
116	Trichoptera	Agrypnia				7	26
117	Trichoptera	Banksiola				7	26
118	Trichoptera	Molanna				7	26
119	Trichoptera	Polycentropus				4	14
120	Odonata	Anisoptera		epitheca		7	26
121	Odonata	Libellula				7	26
122	Odonata	Sympetrum				7	26
123	Odonata	Enallagma				7	26
124	Odonata	Neuroptera		climacia		7	26
125	Odonata	Hemiptera		velidae		7	26
126	Odonata	Hemiptera		notonectids		7	26
127	Odonata	Magaloptera		sialis		7	26
128	Odonata	Lepidoptera		pyralidae eoparagyralis		7	26
129	Diptera	Bezzia				7	26
130	Diptera	Sphaeroma				4	14
131	Diptera	Chaoborus		albatrus		7	26
132	Diptera	Chaoborus		punctipennis		7	26
133	Diptera	Alabesmyia				7	26
134	Diptera	Clinotanyptus				7	26
135	Diptera	Djalmabatista				7	26
136	Diptera	Guttipelopia				7	26
137	Diptera	Larsia				7	26
138	Diptera	Macropelopia				7	26

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139	Diptera	Procladius	3	7	26
140	Diptera	Chaetocladius	2	4	14
141	Diptera	Corynoneura	2	4	14
142	Diptera	Cricotopus	2	4	14
143	Diptera	Nannocladius	2	4	14
144	Diptera	Micropsectra	2	4	14
145	Diptera	Paratanytarsus	2	4	14
146	Diptera	Chironomus	2	4	14
147	Diptera	Cladopelma	2	4	14
148	Diptera	Cryptochironomus	2	4	14
149	Diptera	Endochironomus	3	7	26
150	Diptera	Glyptotendipes	2	4	14
151	Diptera	Microtendipes	2	4	14
152	Diptera	Parachironomus	2	4	14
153	Diptera	Paratendipes	2	4	14
154	Diptera	Polypedium	2	4	14
155	Diptera	Pseudochironomus	2	4	14
156	Diptera	Stenochironomus	2	4	14
157	Diptera	Stictochironomus	2	4	14
158	Diptera	Xenochironomus	3	7	26
159	Mollusca	Elivalvia sp. clecium	2	4	14
160	Mollusca	Campeloma	2	4	14
161	Mollusca	Sphaeriidae	2	4	14
162	Annelida	Oligochaete sp.	2	4	14
163	Annelida	Hirudinea sp.	3	7	26
164	Turbellaria	Tricladida	3	7	26
165	Amphipoda	Crangonyx	3	8	30
166	Porifera	Spongilla	2	4	14
167	Porifera	Epiphydia	2	4	14
168	Porifera	Coromyenia everetti	2	4	14

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169	Arthropoda	Hydracarina							
170	Pisces	Perca	flavescens		3			7	26
171	Pisces	Micropterus	salmoides		3			8	30
172	Pisces	Ambloplites	rupestris		3			8	30
173	Pisces	Pomoxis	nigromaculatus		3			8	30
174	Pisces	Umbra			3			7	26
175	Pisces	Notemigonus	crysoleucus		3			8	30
176	Diptera	Tanytarsus			2			4	14