An assessment of algal biodiversity and water quality in Loughs Atedaun, Cullaun and Inchiquin, three lakes on the river Fergus

Shane Cullinane

Thesis submitted for the degree of Master of Arts

2012

An assessment of algal biodiversity and water quality in Loughs Atedaun, Cullaun and Inchiquin, three lakes on the river Fergus.

Thesis submitted for the degree of Master of Arts

By

Shane Cullinane

B.A (Mary Immaculate College, University of Limerick)

Supervisor: Dr. Catherine Dalton

Department of Geography

Mary Immaculate College

University of Limerick

Submitted to the University of Limerick, February 2012

Abstract

Title of thesis: An assessment of algal biodiversity and water quality in Lough Atedaun, Cullaun and Inchiquin, Co. Clare

This study uses limnological techniques and numerical methods to examine the periphyton and phytoplankton assemblages of Lough Atedaun, Cullaun and Inchiquin. Monthly and seasonal variations in periphyton and phytoplankton assemblages were examined from littoral and open water sites within each lake. Samples were taken on a monthly basis in each lake from November 2004 to October 2005. Cell biovolume values for the most abundant phytoplankton were calculated for each of the phytoplankton samples taken from Lough Atedaun, Cullaun and Inchiquin. Seasonal changes in environmental variables were described on a monthly and seasonal basis and the trophic status of each lake was examined. The influence of environmental variables, between site variation and time of sampling on the distribution and composition of the phytoplankton based on cell count data was investigated with the use of Canonical Correspondents Analysis. (CCA).

Results from physico-chemical analysis showed that a seasonal pattern of change existed for most variables. Very little inter lake differences were found in relation to variables concerned with ion exchange such as conductivity and alkalinity. Where as significant inter lake differences took place in relation to variables concerned with nutrient status such as TP, DMRP and NO_3-N. A total of 100 phytoplankton species were identified within the three lakes, 72 of these 100 species were found in Lough Inchiquin, 54 in Lough Cullaun and 64 in Lough Atedaun. Of the 100 species identified 37 belonged to the phylum Chlorophyta, 25 to phylum Bacillariophyta, 23 to phylum Cyanophyta, 6 to phylum Chrysophyta, 3 to phylum Cryptophyta, 2 to phylum Pyrrophyta and 4 to phylum Euglenophyta. A total of 137 periphyton species been identified from all 3 lakes, 37 of these were Chlorophytes, 45 of these were Cyanophytes and 45 of these were diatoms.

CCA analysis identified two main groups of variables influencing algal diversity. The primary gradient consisted of a species response to temperature, water level variation and chlorophyll-*a* representing a seasonal gradient. The second gradient related to a

response to nutrient variables TP, $N0_3$-N and DMRP confirming that phytoplankton composition of is strongly influenced by trophic state.

Declaration

I hereby declare that this thesis represents my work and has not been submitted in whole or in part, by me or another person for the purpose of obtaining any other qualifications.

Author: Shane Cullinane

Signed:

Date**:**

Dedication

This thesis is dedicated to Sinead,
Without your sacrifice, endurance and love this thesis would not have been possible.
Thanks

Acknowledgements

I would like to acknowledge and thank my supervisor Dr. Catherine Dalton for constantly being there to guide and support me through my M.A. Her valued advice and assistance improved both this thesis and my own professional standards. This work was funded by the Irish Environmental Protection Agency (Project # 2004-SS-30-M1) and Mary Immaculate College Research Directorate.

I would also like to thank Dr. Norman Allott in the Environmental Science Department in Trinity College Dublin for analysis of waters samples and water chemistry results. Thanks also to Prof. Brian Whitton of Durham University and David John for training in algal identification and also for their help with algal taxonomy throughout the course of this project.

I am especially grateful to Guangjie Chen for his advice, encouragement and friendship throughout this project. Many thanks also to all those in Mary Immaculate College especially those working in reception and inter library loans. I would also like to thank Des McCafferty for his support throughout my time in Mary Immaculate College.

I owe a very special thanks to my parents John and Maura who have always been there. I would also like to thank my sisters Caoimhe and Grainne for all kinds of help and support. I would also to thank my children Abigail, Jack, Cillian and Caoimhe you're all little bundles of joy!

Thank You!

Table of Contents

List of tables

List of Figures

Chapter 1

Introduction

Algae are abundant and ancient organisms that can be found in virtually every ecosystem in the biosphere (Graham & Wilcox, 2000). In lake systems planktonic algae live in the open water and periphytic algae live in the littoral (benthic) areas usually attached to rock substrates, both of these algal types will be examined in this study.

In recent years anthropogenic impacts have been a major influence on the nutrient status and biological composition of lakes. The main form of this impact is eutrophication and the main cause in Ireland is increased phosphorus levels as a result of either point source domestic sewage or diffuse run off from intensive farming practices (Wilson *et al.*, 1998; Daly & Casey 2003). Eutrophication is the phenomenon of nutrient overload resulting in highly turbid conditions and algal blooms. In Ireland nutrient overload has been highlighted in recent EPA reports (Lucy *et al.*, 1999; Jennings *et al.*, 2000; Toner *et al.*, 2005). In lakes eutrophication can be a result of several possibilities, inadequate sewage treatment of urban effluent (as in Lough Ennell), seasonally high densities of tourists (Lough Leane in Killarney), diffuse agricultural runoff, rural housing and agric-industry (Lough Derg) and intensive agriculture (piggeries) and leaching as in Lough Sheelin (Reynolds, 1998). The most obvious manifestation of eutrophication in a lake is in the plankton community; increased phosphorus levels will lead to increased algal productivity. Surface scums or toxic blooms as well as reduced water quality and other effects on the biological elements within a freshwater system occur as a result of eutrophication. Species composition is altered, productivity can increase dramatically and certain species especially of the Cyanophyte group can then exploit these circumstances.

The principal method of lake classification in Ireland has been via the use of physical and chemical factors according to OCED (1982) guidelines. Although algae were recognised as important biological elements within aquatic ecosystems, their importance within our natural environment had not been supported until recently by any legal monitoring requirements. This changed in Europe as a whole with the introduction of the European Union Water Framework Directive (WFD) in December 2003 which seeks to protect specific uses of water with the protection of the aquatic ecosystem to achieve good status in all waters (European Union, 2000; Toner *et al.*,

2005). The definition of good status for the first time legally included ecological status as well as the traditionally used chemical status.

The main aim of the WFD is to achieve good ecological status, assessed with reference to biological elements (aquatic flora, fish and benthic invertebrates) and a number of hydrological, physical and chemical measures (European Union, 2000). The WFD set out guidelines in relation to the need to assess both the phytoplankton and phytobenthos within aquatic habitats. The algal community are now recognised legally as been an essential part of the aquatic environment. The WFD set out sampling guidelines which it deemed were necessary in order for a realistic representation of the algal community to be developed. This has had significant implications for algal investigations in Ireland and elsewhere, with algae now seen as an integral part of the aquatic environment and a useful bio-indicator (Irvine *et al.*, 2001, McNally, 2009).

This research aims to examine monthly change in the periphyton and phytoplankton communities of three lakes over an annual cycle and their response to nutrient state. Key project objectives are as follows:

1. Examine variation in the physical and chemical characteristics of three interconnected lakes on a monthly basis over an annual cycle via the use of standard limnological methods.

2. Reassess the trophic classification of each lake.

3. Examine the taxonomic composition of the algae in the open (phytoplankton) waters of these lakes on a monthly basis over an annual cycle using a wide range of biological indices and measures.

4. Examine the taxonomic composition of the algae in the littoral (phytoplankton) waters of these lakes on a monthly basis over a 10 month period.

5. Measure the biovolume of the most common phytoplankton species and to compare the use of algal cell counts and algal biovolume values as bio-indicators.

6. Utilise multivariate ordination analysis to explore phytoplankton variation and response to environmental variables.

To provide a context for this study, Chapter 2 introduces the different algal groups and their major taxonomic details. This chapter also describes the effect of the most significant factors that influence the species composition of algal communities in lakes of different trophic status. Details of the study site selection and their catchment characteristics are included in Chapter 3. Chapter 4 describes the different field, laboratory and data analysis methods employed in the study. In Chapter 5 monthly and seasonal variation in each of the measured environmental variables is described along with the trophic classification of each lake. In Chapter 6 a detailed examination of the algal assemblages found in each sample is described. Monthly and seasonal changes are described in terms of cell count, species richness, evenness, relative abundance and biovolume. Chapter 7 describes monthly and seasonal changes in the periphyton flora. In Chapter 8 relationships between the measured environmental variables and the phytoplankton communities are examined with the use of ordination analysis. Finally, the results of this exploration of algal assemblages in Lough's Atedaun, Cullaun and Inchiquin are compared to other national and international studies in Chapter 9. This chapter also includes some recommendations for future work.

Chapter 2

Literature Review

This project will examine the water quality and ecology of phytoplankton and phytobenthos in Loughs Atedaun, Cullaun and Inchiquin, three lakes situated on the river Fergus in Co. Clare. In this chapter topics such as algae taxonomy, seasonal succession, habitat preference and the key factors affecting spatial and temporal algal dynamics are reviewed. The role of algae as ecological indicators and the regulatory background affecting algal sampling are also discussed.

2.1 Algae

The classification of algae into different divisions is a highly complex area and has undergone much revision in the last 50 years (John *et al.*, 2002). This in part has been due to advances in molecular biology, which have resulted in some species being reclassified. The application of scanning electron microscopy, ultra structural studies, and other studies and techniques (RNA sequencing, DNA hybridisation) has highlighted the variety, wealth and complexity of phytoplankton (John *et al.*, 2002). Part of the complexity associated with algal taxonomy is also due to the differing methodologies used and the variety of classification systems that have been developed. Stevenson *et al.*, (1996) highlight between 4 and 13 algal divisions, 24 classes and approximately 26,000 species. A recent checklist of the freshwater and terrestrial algae of Great Britain and the Republic of Ireland, reported about 5000 species (John *et al.*, 2002). When the term algae is used in this text it is referring to both phytoplankton and periphyton, though when referring to either algal type separately, they are referred to by their specific name i.e. phytoplankton or periphyton. The different algal groups are listed in the Table 2.1 and discussed in the following section.

2.1.1 Cyanobacteria

Modern Cyanobacteria are recognised for their ability to occupy extreme habitats and are valued for their ability to fix atmospheric nitrogen, bind and enrich soils, and produce medicinally useful compounds (Graham & Wilcox, 2000). In terms of water quality Cyanobacteria are of concern when they form nuisance blooms, especially when they produce toxins. This can often occur when a water body becomes over enriched with nutrients as a result of eutrophication (Reynolds & Peterson, 2000). Controversy surrounds Cyanobacteria due to the different classifications, which have

been attributed to the phylum. Cyanobacteria differ to other phyla because they are prokaryotes which means that their cell contents are not separated into membrane-bound structures such as the nucleus and chloroplast (John *et al.*, 2002). This means Cyanobacteria are structurally and physiologically like bacteria, but they photosynthesise like plants in aquatic habitats (Wetzel, 2001).

Table 2.1 Algal groups (Phyla) and some commonly used descriptive terms

Algal Groups (Phyla)	**Commonly used names**
Cyanophyta	Blue green algae (Cyanobacteria)
Rhodophyta	Red algae
Euglenophyta	Euglenoids
Cryptophyta	Cryptomonads
Pyrrophyta (Dinophyta)	Dinoflagellates
Raphidophyta	
Haptophyta	
Chrysophyta	Golden (Brown) algae
Xantophyta (Tribophyta)	Yellow green algae
Eustigmatophyta	
Bacillariophyta	Diatoms
Phaeophyta (Fucophytas)	Brown algae
Pyrrophyta	
Chlorophyta	Green algae
Glaucophyta	

Cyanobacteria can occur in filamentous (*Anabaena, Oscillatoria, Aphanizomenon, Gleotrichia*), unicellular (*Coelosphaerium, Microcystis*) and colonial (*Coelosphaerium, Microcystis*) forms. In filamentous form cells are usually arranged end to end to form trichomes. These trichomes are sometimes contained within a mucilaginous sheath. Akinetes occur in a number of species in the form of enlarged, thick walled cells, these cells store protein that accumulates in the form of cyanophin granules. Heterocysts are another cell type which are unique to Cyanobacteria, they occur in many filamentous species, but are absent from the *Oscillatoriaceae* group, an example would be *Anabaena*. Heterocysts are typically smaller than akinetes and not much larger than vegetative cells. Some of the more general morphological

characteristics that can aid in identifying a genus or species to be a part of the Cyanobacteria family are cells lacking chloroplasts. Cell pigmentation (blue-green, grey green, violet, olive green, purplish or reddish) is more generally distributed throughout the cell; sheaths when present are often coloured and are typically yellow-brown; nucleus absent (prokaryotic) (John *et al.*, 2002).

2.1.2 Chlorophyta

The Chlorophyta (green algae) are one of the most species rich and morphologically diverse groups. In the British Isles there are around 250 known genera. Historically it was one of the first phyla to be explored, and this is due to the wide variety of terrestrial and aquatic habitats that it can occupy (John *et al.*, 2002). One species *Trentopholia* often forms on the sides of houses in the west of Ireland, leaving an orange red marking. They can also occur in marine environments e.g. the sea lettuce *Ulva*. Graham & Wilcox (2000) have outlined many useful benefits which result from green algae, such as being a source of oil (*Botrycoccus*), acting as a bio-indicator (*Selenastrum*) or even as a human food supplement (*Chloreal*).

The Chlorophyte group consist of unicells (*Chlamydomonas, Coccomonas, Carteria*), colonies (*Botrycoccus, Volvox, Gonium, Pandorina*), and filaments (*Oedigonium, Klebsormidium, Spirogyra, Desmidium*) (John *et al.*, 2002). There are also motile unicells and colonies. Unicells and colonies are usually microscopic, but they can range from just a few microns in diameter (a *Chlorella* cell) to at least a metre (*Hydrodicyton* nets) in length. Cells are usually light to dark grass-green. Only a few taxa are red, orange or yellow due to presence of masking pigments e.g. *Haematoccus, Trentophila and Botrycoccus* (John *et al.*, 2002). Features that are common to almost all of the green algae include*:* flagella, commonly occurring in pairs or multiples of two that are approximately equal length. Some of the characteristics that would aid in identifying a species are cell colour, shape, and size, number of flagella and chloroplast shape .

2.1.3 Bacillariophyta

Diatoms occur in all aquatic habitats. They may be planktonic (open water), epilithic (growing on stones on shore area), periphytic (growing on plant or other surfaces)

epizoic (on animals) or endozoic (within e.g. foraminifera); they can also occur in terrestrial habitats (Round *et al.,* 1990). In terms of evolutionary diversification, the diatoms have been widely successful with 285 genera encompassing 10,000-12,000 recognised species. Diatom diversity is rivalled only among the algae by the green algae (Round *et al.*, 1990).

The primary characteristic of a diatom is its silicified cell wall. It is for this reason that diatoms can survive morphologically beyond their life span and be of use for palaeolimnological studies. The cell wall or frustules of diatoms consists of two lid-like valves, one of which fits within the other. Both valves overlap one another in what is known as a girdle. The various structures of the siliceous cell walls of diatoms are used in the identification of species. Diatoms can occur as unicells (*Rhizolenia, Navicula, Nitzschia,* and *Pinnularia*), colonies (*Tabellaria, Fragilaria*) and filaments (*Tetracyclus,*) (Wetzel, 2001). Symmetrical differences in diatom morphology help distinguish species from one another (Cox, 1996). There are circular or centric diatoms and elongate or pennate diatoms. The centric forms often have a radial symmetry and lack a raphe system. A raphe is a longitudinal split or opening found on one or both walls (Trainor, 1978). The pennate forms generally have a bilateral symmetry, possess fewer plastids (frequently two per cell) and may possess a raphe system (Trainor, 1978; Round *et al.*, 1990).

2.1.4 Euglenophyta

Euglenoids are usually found in environments where there is an abundance of decaying organic matter such as marshes, bogs, fens or mires essentially brown peat water systems. Due to their association with increased levels of dissolved organics, euglenoids have been used as environmental indicators of such conditions (Wetzel, 2001). The Euglenophytes or euglenoids contain about 44 free-living genera and more than 800 species. Most are colourless with phagotrophic or heterotrophic modes of nutrition, but about one third are green and phototrophic. Wetzel (2001) documents how few species are truly planktonic and most are periphytic, living attached to substrate. The euglenoids usually occur mostly as flagellated unicells. The size and shape of the cells vary considerably even in a single organism. They are motile and can move with the aid of flagella. Some of the better-known species are *Trachlemonas, Euglena* and *Phacus* these are unicellular species. Morphological

features to look out for when trying to differentiate one species from another are the eyespot, nucleus, pocket (reservoir) and contractile vacuole (John *et al.*, 2002).

2.1.5 Pyrrophyta

Dinoflagellates are so called for the twirling motion by which they move. They are a well-known species due to the red tides, which they can cause in marine environments (John *et al.*, 2002). The dinoflagellates are unicellular flagellated algae, many of which are motile. A few species are naked or without cell wall (*Gymnodinium*). Most develop a conspicuous cell wall that often is sculptured with large spines and elaborate cell wall processes (John *et al.*, 2002). These organisms occur as flagellates or sessile (non motile) unicells, colonies and filamentous forms. The cells are typically flattened and have a transverse constriction, the girdle, usually found in the middle of the cell (Wetzel, 2001).

2.1.6 Chrysophyta

Chrysophytes often exhibit a distinctive golden brown colouration because of the dominance of B-carotene and specific xanthophylls carotenoids in addition to chlorophyll-a. Other groups of algae also contain golden brown plastids illustrating some of the complexity of classifying algal species (Graham & Wilcox, 2000). The Chrysophytes number about 1000 species. Most are unicellular or colonial flagellates, predominantly occurring in freshwater plankton (John *et al.*, 2002). The majority of the Chrysophycean are unicellular (*Chromulina, Chrysoccus* and *Mallomonas* (all with a single flagellum), a few are colonial (*Dinobryon, Synura, Chrysophaerela, Uroglena*) and they are rarely filamentous (*Tribonema*) (John *et al.*, 2002).

2.1.7 Cryptophyta

Cryptomonads mainly occur as unicellular algae with flagella. This phylum is common within many limnological studies in temperate lakes. *Rhodomonas*, *Cryptomonas*, and *Chroomonas* are three genus which have been found in previous limnological studies in Ireland (Irvine *et al.*, 2001, Free 2002). Distinctive morphological features are the appearance of flagella, chloroplast shape and cell shape (John *et al.*, 2002).

2.2 Algal size

The measurement of algal cell size is recognised as an important aspect in algal studies (Wetzel, 2001). This is because cell size is related to cell biovolume (the total area of an algal cell when measured) and this is an important measurement when studying the role of algae within an aquatic habitat (Sun & Dongyan, 2003). It is common now for limnologists to categorise algal communities on the basis of organism size instead of the more traditional phylogentic approach (Kalff, 2001). Graham & Wilcox (2001) state that size is the most important single characteristic affecting the ecology of phytoplankton. Size classifications for algae are shown in the Table 2.2.

Table 2.2 Classification of algae according to size (Wetzel, 2001)

Plankton type	**Size**
Picophytoplankton	< 1µm
Ultraplankton	1- 20µm
Microplankton	20-200µm

Picophytoplankton consist mainly of small coccoid Cyanobacteria of the *Synechoccus* type, commonly of a size less than 1µm and occupy diverse habitats over a wide range of temperatures, light, salinity, and nutrients. The ultraplankton are simple, unicellular in from, and have generation times in hours. The microplankton consists of larger algae such as diatoms which tend to be nonmotile and depend upon mixing to remain suspended in the photic zone. Other phyla such as the Euglenophytes or certain Cyanobacteria compete most effectively under stable water conditions where buoyancy and motility allow for cells to achieve an optimum position in order to access light and nutrients.

2.3 Seasonal succession in phytoplankton communities

This section will discuss how various physical, chemical and biological variables control algal growth rates both temporally and spatially. The seasonal succession of phytoplankton has been the subject of intense study, to the extent that the general patterns or cycles of phytoplankton growth in temperate lakes are now well

understood (Hutchinson 1944/1957; Reynolds 1980/1984; Allott, 1986/1990; Reynolds *et al.*, 1998; Reynolds & Peterson 2000; Wetzel, 2001; Irvine *et al.*, 2001). Reynolds (1984) describes six different cycles that have occurred in different lakes. In his examination he details the cycles of lakes with different trophic states. Wetzel (2001) separated algal growth cycles into eight different periods; these are, midwinter, late winter, spring circulation, initial summer stratification, summer clearwater phase, latter part of summer stratification, fall circulation and late autumn decline. Therefore the four seasons (winter, spring, summer and autumn) are an essential primary pattern in algal dynamics.

In most temperate lakes the winter minimum is made up of small flagellates adapted to low light and temperature. The low light levels in winter as well as the low levels of light penetration accompanied by low temperatures result in low algal populations as well as very little species diversity (Kalff, 2001). In temperate lakes in Ireland, strong winter winds that occur especially near the Atlantic seaboard can result in all but the deepest lakes becoming fully mixed (Allott, 1986/1990). This is another factor combined with light and temperature that results in algal populations as well as algal biomass reaching its annual minimum during winter.

During spring temperatures are still low but increasing, light conditions are mixed but beginning to increase, nutrient availability is high and the water column is still mixing as in winter (Wetzel, 2001). As spring moves on the increase in light and temperature sparks the beginning of a period of rapid phytoplankton growth. A relatively large amount of nutrients are still within the water at this stage. The rapidly growing plankton community thrive on these available nutrients. Very little pressure occurs from grazing at this stage. The spring bloom is usually dominated by diatoms in temperate lakes e.g. *Asterionella*, *Stephanodiscus* or *Cyclotella* (Scheffer, 2004). As temperatures are still low in spring it is the increased light availability that has the greatest effect on the growth in algal populations.

Summer sees the onset of stratification in deep lakes that results in the water column being distinguished into different layers according to differing water temperatures (Irvine *et al.*, 2001). The reduction in mixing as a result of less wind sees a concurrent reduction in the recycling of nutrients as well as nutrient availability reaching an annual low. Higher air temperatures result in the water column increasing in

temperature while the increased availability of light sees an increase in photosynthesis and plant growth. Grazing upon the plankton community increases as a result of a greater quantity of zooplankton and other grazers. In lakes of a high trophic category (i.e those with higher nutrient levels) late summer can see a dominance of algae from the Cyanophyta group, especially those with the ability to fix nitrogen from the atmosphere in the form of N_2. This can lead to the development of nuisance blooms (Brönmark & Hansson, 2005).

In autumn the water mixes and decreases in temperature, light availability declines and grazing by zooplankton is reduced (Wetzel, 2001). Phytoplankton biomass is still high with large unicellular algae like the Euglenophytes and Cryptohytes as well as filamentous algae dominating during this period. The end of autumn then sees a marked reduction in algal biomass and populations as well as low light and temperature availability as algal populations return to winter lows.

2.4 Factors affecting algal growth

Phytoplankton are suspended in the water column whilst benthic (periphytic) algae are those that live on or in association with substrata. Algae may be benthic or planktonic, but many species are characteristically found in one habitat (Wetzel, 2001). The most dominant phyla in benthic environments are Bacillariophyta, Cyanobacteria and Chlorophytes (Round *et al.*, 1990). Planktonic habitats support these algae along with Chrysophytes, Xanthophytes, Cryptophytes and Pyrophytes (Reynolds, 1984). These phyla can also be found in benthic environments but often while going through a resting stage, after settling there from the water column (Reynolds, 1984).

Planktonic and benthic algae are essential to the health of the lakes which they inhabit. Benthic algae are important and even dominant primary producers in many shallow lakes and ponds, whilst the importance of planktonic algae has been well documented (Reynolds, 1984; Cattaneo, 1987; Irvine *et al.*, 2001; Wetzel, 2001). Benthic habitats in an aquatic ecosystem are thought to have a greater diversity in nutrient conditions than planktonic habitats within the same system (Hansson, 1992; King *et al*., 2000). Grazing and mortality rates may operate at differing degrees in phytoplanktonic and benthic communities. Substrate availability can also limit the

spatial development of benthic algae (Hansson, 1992). The most influential factors affecting algae are outlined in Tables 2.3 and 2.4. Table 2.3 lists the physical, edaphic (chemical), morphological (physical and hydrological) and biological factors that affect phytoplankton growth. This can be compared to Table 2.4, which lists the main physical, chemical and biological factors that affect periphyton growth. The only factor that does not affect both types of algae is substrate which only affects periphytic algae.

Table 2.3 Main ecological variables of a limnological system out of a trophic framework that are related to phytoplankton (adapted from Rojo, 1998)

Abiotic		**Biotic**	
Physical	**Edaphic**	**Morphological**	**Community**
Transparency	Conductivity		Zooplankton
Light availability	TN,DIN,SRP	Mixing regime	Biomass of fish
PAR attenuation	CO_2	latitude	Biomass of bacteria
Temperature	pH	Turbulence	
N^2	TN: TP	Depth and shape of lake	
Seasonality	DOM	Hydraulic disturbance	
	Acidification		
	Carbonacceous		

Table 2.4 Physical, chemical and biological factors that influence the epilithic algal assemblage (adapted from Trainor, 1978)

Physical	**Chemical**	**Biological**
Light	Nutrient levels	Competition
Substrate	Growth requirements	Effect of organisms on available light, nutrients etc
Water temperature	Nutrient increase i.e. eutrophication	Grazing
Current velocity and flood occurrence	Extra cellular products	
Rain	Pollution	
	Buffering and pH values	
	Oxygen availability	

The most influential factors affecting algae will now be discussed under the following headings; light and temperature, thermal stratification, photosynthesis, growth and nutrient uptake, seasonal succession of phytoplankton, competitive interactions amongst algae, mortality and grazing and anthropogenic impacts on algae.

2.4.1 Light and temperature

Each species of algae has an optimum and tolerance range beyond which it could not survive (Wetzel, 2001). Changes in temperature can affect algal growth rates directly and indirectly through the effects of temperature on water mass and thermal stratification (Trainor, 1978). In laboratory studies on cultured algal species different species have been shown to have an optimum temperature tolerance range (Reynolds, 1980; Rojo, 1998; Stevenson and Stoermer, 1981). It has been shown that a species can have an optimum temperature for photosynthesis, for general metabolism and for sexual reproduction. The ability of a species to adapt to different temperatures will often influence its ability to survive. (John *et al.*, 2002). Wetzel (2001) states that for many diatoms the critical temperature is about $5^{\circ}C$ whilst for other species it can be about $15^{\circ}C$. In the field it has been noted that blooms of blue green algae tend to occur in summer when temperatures are on the increase or reaching their annual maximum important (Allot 1986 & 1990; Scheffer, 2004). It has been shown that temperature can have a direct effect on algae but its indirect effects such as thermal stratification can be more profound.

2.4.2 Thermal stratification

Thermal stratification is a physical process, which occurs within lakes due to the molecular composition of water, which then has serious knock on effects for the entire lake ecology. The process of thermal stratification separates a lake into distinct thermal layers or strata. The upper warm less dense layer is called the epilimnion. The lower cooler (lower) dense layer is known as the hypolimnion, between these two layers lies a region of sharp change in temperature known as the metalimnion. As solar radiation and wind turbulence is not constant throughout the year, the stratification is not permanent but varies throughout the seasons. Brönmark & Hansson (2003) state that the temporal pattern of temperature and especially the

formation of the thermocline is the most important physical event for the structure and function of a lake and this can seriously affect a lakes biota.

Temperature differences can develop in almost all lakes down through the water column. Differences can be larger in some lakes than in others though this will depend on several factors such as lake location, altitude, area, depth, and exposure. A variety of physical and chemical variables will control the level of stratification. Thermal stratification then has a direct impact on the spatial and temporal distribution of the algae and the remainder of the lakes biology (Reynolds 1980/1984; Allott, 1990; Watson *et al.,* 1997; Reynolds *et al.,* 1998; Wetzel, 2001; Scheffer, 2004). The mixing caused by wind currents also has an effect on the level of turbidity within the lake which will then have an effect on the level of irradiance which can penetrate to the algae. If a lake is turbid due to mixing from an increased wind force then the rate of photosynthesis and algal growth will be reduced (Brönmark & Hansson, 2003).

This process of stratification has important consequences for phytoplankton, certain species which prefer warmer water may move and mix through the epilimnion whilst those which prefer colder temperatures may stay within the metalimnion (Reynolds, 1984). Currents generated by wind movement will also effect the spatial distribution of the algal populations within the lake. A westerly wind over a few days will result in the majority of the phytoplankton communities being spread along the eastern shore of the lake. Stratification can also have a significant effect upon nutrient recycling; nutrients will be moved around a lake within currents and therefore will affect different algal habitats and the levels of diversity within the lake (Reynolds, 1984).

2.4.3 Photosynthesis

Photosynthesis is a biochemical process, which transforms the radiant energy of light into potential energy. The most fundamental aspect of phytoplankton ecology is the ability of species to process light energy into biomass through photosynthesis (Graham & Wilcox, 2000). The ecological effects of light and temperature on the photosynthesis and growth of algae are difficult to separate because of interrelationships between light and temperature. Photosynthetic pigment composition and concentration varies amongst the differing algal groups. Cyanobacteria have no

chloroplast and the pigments are distributed throughout the cell cytoplasm (John *et al.*, 2002).

Many experiments have been conducted to analyse the relationship between phytoplankton and light intensity. Culture studies completed within laboratories have lead to plant physiologists and limnologists being able to quantify the differing levels of photosynthesis, which take place in different algal species (Nalewajiko & Dean, 1978; Lehman & Sandgren, 1985; Hansson, 1992). Rates of photosynthesis have been discovered as well as the creation of a series of terms to describe how different algal species function under different levels of light (Reynolds, 1984; Stevenson *et al.*, 1996; Graham & Wilcox, 2000; Wetzel, 2001; Kalff, 2002; Scheffer, 2004).

2.4.4 Growth and Nutrient uptake

Algal cells have been intensely studied to determine cell structure not just morphologically but also in terms of nutrient uptake and nutrient limitation. Lakes are dynamic environments; their nutrient state is influenced by external factors such as geological, meteorological, ecological, catchment and anthropogenic changes. Internal influences also exist as a result of complex uptake and feedback relationships, which occur between the nutrients within the lake and a lakes plant and algal communities. It is known that around twenty or so elements are contained in algal tissue. Reynolds stated that of these 20 elements, 11 are macronutrients (C, O, H, N, P, S, K, Mg, Ca, Na and Cl) and are stored as ions within the protoplast whilst the remainder are micronutrients (Fe, Mn, Cu, Zn, B, Si, Mo, V, and Co) which are not less essential to the functioning of the cell (Reynolds, 1984). The three most important elements for algal productivity are phosphorus, nitrogen and silica. Prior to examining these important nutrients it is necessary to discuss how algal cells obtain nutrients from an external medium and also how they contribute themselves to the nutrient status of the medium within which they exist.

Nutrient transfers within lentic ecosystems take place largely between the water column and lake sediments. This involves uptake by phytoplankton, periphyton, zooplankton, bacteria and other consumers as well as sedimentation in both the water column and benthic muds. It is clear that different species have different nutrient requirements and different uptake and growth rates. Some species take up nutrients

faster than others while some species satisfy their needs at lower concentrations. Within an aquatic environment different species will dominate at different times depending upon local conditions and their own inherent ability to deal with those situations. Studies have shown that phosphorus, nitrogen and (in the special case of diatoms) silica are the nutrients whose typically low concentrations in natural waters are most likely to become limiting (Reynolds, 1984; Cattaneo, 1987; Watson *et al*., 1997)

2.4.5 Phosphorus

Historically the relationship between phosphorus and algal growth is one of the most intensely examined relationships within the field of limnology, in fact no other element in freshwaters has been as intensely studied as phosphorus (Carpenter *et al.*, 1992; Jennings *et al.,* 2000; Daly & Casey, 2000). The importance of phosphorus, stems from the fact that of all the major nutrients affecting biota, is the least abundant and most commonly limits biological productivity (Hutchinson, 1944). In freshwaters phosphorus is usually detected in two forms either as soluble reactive phosphorus (SRP) or total phosphorus (TP). SRP is a measure of the quantity of dissolved inorganic phosphorus within freshwaters whilst TP is a measure of the level of total dissolved phosphorus (organic and inorganic). It has been shown in many reports that algal biomass and production in lakes tend to increase due to phosphorus input (Irvine *et al.,* 2001; De Nicola *et al.,* 2003).

Phosphorus is absorbed by algae in a process known as nutrient uptake. Cells have the ability to store excess phosphorus, though some algae are better at this than others and therefore can become the dominant species under certain conditions. Table 2.5 taken from Wetzel (2001) shows the different phosphorus requirements of some common algae.

Table 2.5 The minimum phosphorus requirements per unit cell volume of several algae common to lakes of progressively increasing productivity (Wetzel, 2001)

Algae	**Minimum P requirement ($\mu g\ mm^{-3}$ cell volume)**
Asterionella	<0.2
Fragilaria	0.2-0.35
Tabellaria	0.45-0.6
Scenedesmus	>0.5
Oscillatoria	>0.5
Microcystis	>0.5

This minimum P requirement has been well detailed, especially in the works of Nalewajiko & Dean (1978), Carpenter *et al*., (1992) and Wetzel (2001). Table 2.5 suggests that if *Asterionella* and *Oscillatoria,* were grown together at low external P concentrations, *Asterionella* would dominate as it was better at adapting to the low phosphorus condition (Tillman, 1982; Wetzel, 2001).

2.4.6 Nitrogen

Nitrogen occurs in freshwaters in numerous forms, these are dissolved nitrogen gas (N_2), ionic forms such as ammonium ion (NH^4), nitrite ion (NO^2-) and nitrate ion NO^3-) (Wetzel, 2002). Sources of nitrogen within a lake include precipitation, nitrogen fixation by algae within the water and the sediments as well as inputs from surface and groundwater drainage. In most temperate oliogotrophic and mesotrophic freshwaters, nitrate is present in relative excess and exceeds the supply of phosphorus (Graham & Wilcox, 2000). It can be said then that nitrogen plays a lesser role in low nutrient freshwater systems. In temperate lakes of a eutrophic status where phosphorus levels are very high it has been noted that nitrogen can become an influential factor on algal growth and productivity (John *et al.*, 2002). The supply of phosphorus may exceed the supply of nitrogen in eutrophic waters. Under these circumstances nitrogen-fixing Cyanobacteria such as *Anabaena, Aphanizomenon* and *Gleotrichia* may generate nuisance blooms.

Seasonal fluctuations exist in most temperate lakes in terms of nitrogen rates. Higher concentrations of nitrogen exist during winter whilst in summer nitrogen levels become depleted as algal uptake exceeds the rate of supply and thermal stratification

restricts internal recycling (Reynolds 1984 & 1998). This situation has been found to exist within many Irish lakes and has been detailed by Irvine *et al.,* (2001) and Pybus & Pybus (2001). Many investigations have shown that thermal stratification also has a considerable effect on the spatial movement of nitrogen within a lake. In a eutrophic lake NO^3 exists mainly within the epilimnion and within an oligotrophic lake NO^3 occurs mainly in the hypolimnion (Graham & Wilcox 2001; Wetzel 2001). Nitrogen fixation in the open waters of lakes has been related to the presence of Cyanobacteria that possess a heterocyst. A heterocyst is a specialised cell that occurs in most filamentous Cyanobacteria except for the Oscillatoriaceae.

2.4.7 Silica

Silica is present in most natural waters; sources of silica include the underlying geological bedrock as well as decaying organic material. There are two main forms of silica, particulate silica and silicon dioxide. Particulate silica comes in two forms biotic material such as diatoms and other organisms and inorganic particulates. Silicon dioxide comes from various rock sources. All algae have a requirement for a small amount of silica. Chrysophyta and Bacillariophyta (diatoms) in particular have significant requirements for silica. The diatom cell wall is strengthened by silica, which is taken up by the algal cell. In the diatoms a pair of siliceous frustules constitutes the basic structural unit of the wall; in Chrysophytes the silica is within the delicate scales that cover the cell (Reynolds, 1984). In most temperate lakes winter high silica levels are found in winter a result of increased runoff. Spring sees a reduction in silica as diatom blooms increase and take up silica. Summer sees annual lows in silica levels whilst autumn sees an increase in silica levels as biological uptake decreases, runoff increases and there is an increase in availability of dead organic matter.

2.4.8 Competitive interactions amongst algae

No other subject in phytoplankton ecology seems to generate as much debate as the concept of competition (Graham & Wilcox, 2000). Competition and predation are so intimately tangled, their results so similar that teasing the two apart is difficult. Their relative importance is the source of acrimonious debate (Jeffries & Mills, 1990). This controversy stems from the early work of Hutchinson (1961) when he tried to apply

Gauses competitive exclusion theory and niche theory. However, Hutchinson was unable to apply this paradigm to phytoplankton dynamics and in his attempts he developed the influential theories based around the 'phytoplankton paradox' (Hutchinson, 1957 & 1961). Graham & Wilcox (2000) summarise this paradox as follows: if phytoplankton species were all at or near their carrying capacity and competition were a major force in community structure, how could one explain the coexistence of 50 to 100 species in a millimetre of water under the same conditions? Algal assemblages comprise several species, which are potentially alternative dominants or act as simultaneous co-dominants (Hutchinson, 1957). There is no doubt that certain species are better at adapting to different times of the year e.g. the diatom community dominates in temperate lakes in the spring. With competition though the question must be asked is why the diatom species *Asterionella* would co-dominate with another diatom species over species from other phylum? A core point is that the balance of competition between winners and losers may be responsible for determining how many species can coexist in a habitat (Graham & Wilcox, 2000).

2.4.9 Mortality and grazing

Grazing by zooplankton upon algae obviously results in population losses. Algae form a major part of the diet of a wide range of grazers from amoebae to young fish. Growth and productivity of algal populations are counterbalanced by losses through sedimentation, viral and fungal parasitism and grazing by zooplankton (Wetzel, 2001). Pan & Lowe (1994) found that the accrual rate of *Achnanthes minutissima* continuously decreased with increasing grazer densities, and the mayfly *Baetis tricadatus* effectively depressed *Synedra ulna* populations. In fact the morphology of other species may make certain species more susceptible to grazing and others less susceptible. Taxonomic groups with a small upper size range are also likely to be regulated strongly in lakes with intermediate and high nutrient levels, which support herbivorous zooplankton populations (Watson *et al.*, 1997). It is also known that many of the dinoflagellates such as *Ceratium* and *Phormidium* with their amour plate like exterior are less prone to grazing than many other species (Reynolds, 1984).

2.5 Algae as indicators of water quality

Fish, invertebrates, macrophytes and algae have all been used successfully as bioindicators in lakes, rivers and marine environments. Historically fish and macro-invertebrates were more popular bioindicators compared to algae and macrophytes. Monitoring programmes based on fish can be criticised around the fact that fish are motile and can therefore move from the source of pollution. Macro-invertebrates are popular bioindicators due to the ease of species identification and their shore habitats which were easy to sample. Macrophytes are also good indicators of the ecological status of lakes; many studies have related macrophyte species to environmental gradients and trophic states (Pybus & Pybus, 2001; Irvine *et al.*, 2001). Comparing both benthic algae and macrophytes in terms of their use as bioindicators, Whitton stated that benthic algae may be more valuable than rooted macrophytes as they reflect only the properties of the water, rather than a combination of water and sediments (Whitton & Rott, 1996).

The use of algae as bioindicators has been discussed for almost 100 years. Initially phytoplankton and their relationships with lakes of differing trophic states were established, this lead to the realisation that certain species were more abundant in certain trophic states (Rawson, 1956). Algae and especially diatoms have long been recognised as useful indicators of contemporary environmental variables (Dixit *et al*., 1992). In fact certain algae can be used in order to monitor lakes and thereby can function as biomonitors. Biomonitors are sometimes used to provide early warning of possible environmental deterioration, and may provide sensible measures of pollution (Graham & Wilcox, 2001). Four species that can function as bio monitors are the unicellular green algae *Selenastrum capricornutum* and *Scenedesmus subspicatus* as well as the marine diatoms *Skeletonema costatum* and *Phaeodacytlum tricornutum* (Graham & Wilcox, 2001). Indicator species are those that by their very presence and abundance provide some indication, either qualitatively or quantitatively or both, of the prevailing conditions (Hellawell, 1978). Good indicators should have very clear and well-defined relationships with corresponding environmental parameters. It is often very difficult to find such clear well defined relationships, due to the ability of algae to adapt to different conditions. For a list of the ideal attributes of good indicator species see Hellawell (1978) and Whitton (1996).

There are many advantages to utilising benthic algae as bioindicators; periphyton communities are easy to sample, as they are located along the shoreline. They have been shown to be very useful indicators of changes over intermediate time periods (King *et al.*, 2000; De Nicola *et al.,* 2003 & 2004). In Ireland many shallow lakes have extensive rocky littoral areas which often and produce high rates of benthic algae species and often these areas are likely to be the major contributor to whole lake production (De Nicola *et al*., 2003 & 2004). Studies have demonstrated that the structure of extant, shallow-water, periphyton communities in lakes is significantly related to overlying water chemistry. Regression models have been successfully developed to determine taxa preferences for total phosphorus (TP), total nitrogen (TN), dissolved inorganic carbon (DIC), pH, Ca, Cl, conductivity, and dissolved organic carbon (King *et al*., 2000; De Nicola *et al.,* 2003 & 2004).

2.6 Summary

Physical (e.g. temperature, stratification) and chemical (e.g. TP, N, Si) properties of water have a direct effect on algal dynamics in terms of species turnover and dominance. Physical changes in the water temperature of lakes will change species composition along with thermal stratification, which allows for certain species to prosper. Nutrients such as silica, a major contributor to diatom cell composition, and phosphorus and nitrogen, are important macro nutrients which can affect algal dynamics. Phosphorus in particular is an important limiting nutrient in healthy aquatic systems but as a result of man's activities in catchments nutrient loading is a major issue in many lakes.

Chlorophyta, *Cyanophyta* and *Bacillariophyta* are important algal groups in temperate lake systems. Determination of algal communities is labour intensive however the WFD requires the inclusion of biological examination in order to classify lakes (European Union, 2000). There is a paucity of basic evidence relating to reference assemblages and the seasonal changes in the periphyton and plankton communities in different lake types. Most studies to-date have not been concerned with developing basic floral accounts because of the immense change in composition from week to week and the time taken to determine the separate components of phytoplankton biomass. However, chlorophyll-a, flourimeter and secchi depth measurements are all based on our understanding of basic floral characteristics and knowledge of same will

always be essential. Finally more studies are needed examining the use of biovolume as an algal indicator especially in comparison to the more commonly used indicators of cell count and chlorophyll-a values.

Chapter 3

Study Area

This chapter describes the study area in Co. Clare and study site selection from a range of lakes in the Fergus river catchment.

3.1 Study area

County Clare (Figure 3.1) is situated on the west coast of Ireland between Galway Bay and the estuary of the river Shannon. The county boundary extends from 52º 34' to 53º 08' latitude and from 08º 17' to 09 º 56' longitude (Finch, 1971). It has a relatively mild climate, but can be very wet and windy with an annual mean temperature of 8.9°C. This is linked directly to the predominantly south-westerly winds and frontal depressions that can result in precipitation levels being between 1000 and 1500 mm annually. Mean temperatures in January 2006 were 6.6^{o}C (Irish Meteorological Service in Claremorris c. 40 km north of the Fergus catchment) whilst mean temperatures in July were 15.4 ^{o}C. Total rainfall in January was 69.2 mm and total rainfall in July was 45.2 mm. The number of rain days can range from 175 to 250 per year.

This study is focused on the river Fergus to the south east of the Burren, in an area often referred to as the Gort lowlands. The Gort lowlands form a low-lying corridor running from the Shannon estuary in the south of the county to the north of the county near to Galway Bay. The river Fergus rises in the Burren region of North Clare and flows southward towards the village of Corofin and the town of Ennis to join the tidal waters of the Shannon Estuary at Newmarket on Fergus. The Fergus River originates in Lough Fergus at 87 m O.D. on the impermeable Namurian strata and collects various tributaries, before sinking underground at the contact with the limestone (Drew, 1988a). The river course includes some modified stretches created by drainage engineers in the nineteenth century and a large proportion of the river does not follow a surface course but takes a series of shortcuts via swallow holes in the river beds and lake shores emerging as springs which feed the river further on down the catchment (Coxon, 1995; Drew 1988 a & b; Coxon & Drew 2000). These pathways affect the hydrology of many of the lakes, with most lakes being fed by over ground and underground channels. The abundance of underground channels also makes certain areas prone to flooding during winter. In the upper part of the catchment the river follows both a surface course as well as being highly influenced by a series of underground springs and streams, which are typical of a carboniferous karstic

limestone region. In the lower part of the catchment the river follows a largely surface course as it flows southward (Coxon, 1995; Drew, 1988 a & b). A network of lakes of varying sizes, are situated along the main river and also along the tributaries that flow into it. The river has salmon, brown trout, pike, perch, bream, tench, rudd and eels. The spectacular scenery, which surrounds the Fergus especially its northern section in the Burren, attracts many visitors.

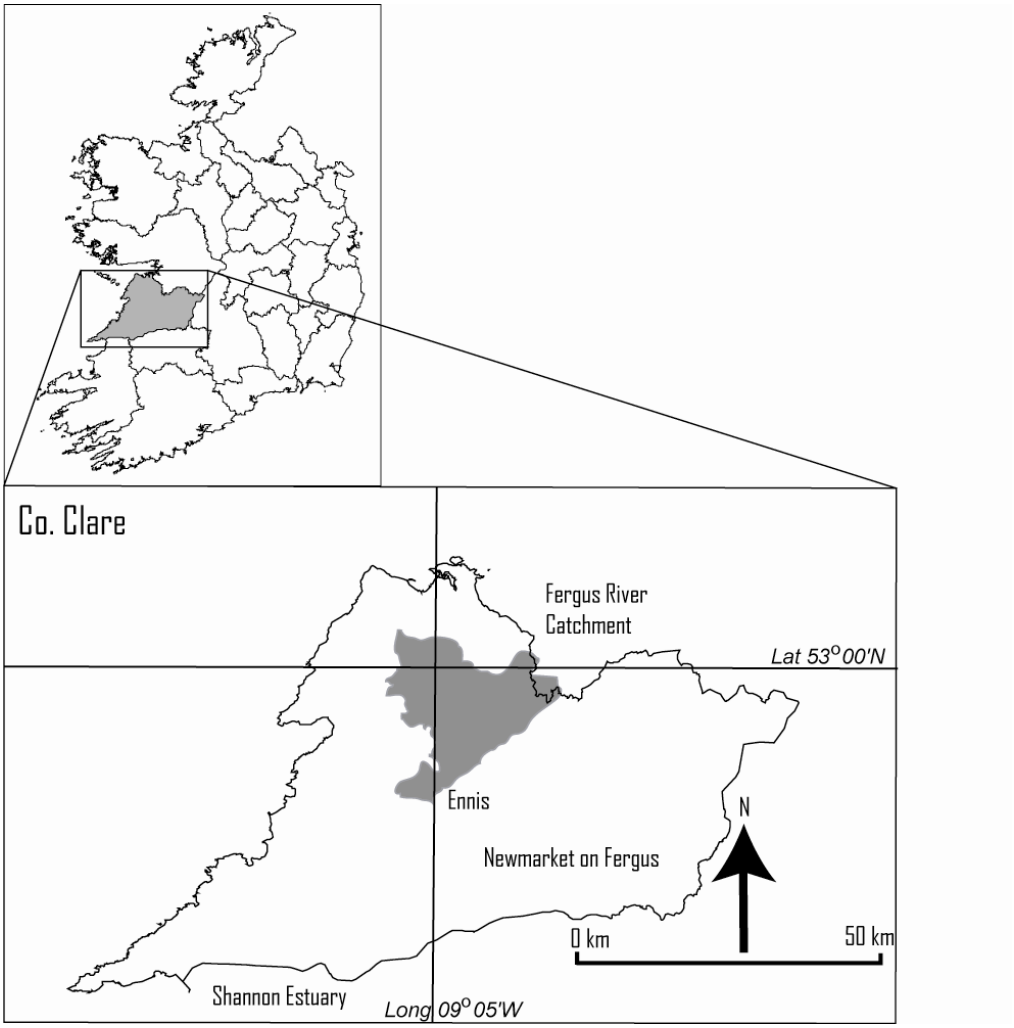


Figure 3.1 Study area in County Clare and the Fergus River catchment

The dominant rock type in the upper part of the Fergus catchment is Upper Carboniferous limestone. To the north east of this area are the Slieve Aughty mountains, which are a mixture of Old Red Sandstone and less dominant Silurian Quartzite. To the south west of the study area are the Clare hills, where shale forms a continuous layer overlaying most of the limestone. The limestone is extremely bare in some areas within the upper part of the catchment whilst in the south the limestone is overlain by patchy cover of glacial deposits, mostly limestone till dating from the last glaciation (Finch, 1971). In lowland regions these deposits can form into drumlin ridges, rising 15-30 metres above the flat lowland, while elsewhere it is generally less than three metres thick and in some places absent. Thin rendzina soils have developed directly over the limestone bedrock (Coxon, 1995). The western part of the catchment is dominated by soils which have poor drainage capabilities, weak structure and heavy texture. According to the national soil survey of Ireland (Finch, 1971) this area is regarded at a poor level for both tillage and grassland farming. The northeastern part of the catchment has very shallow soil over bedrock, while the southeast has some pockets of soil which would be good for tillage farming, but the majority of the area is dominated by shallow soils, with a weak structure that are sometimes prone to flooding.

3.2 Site Selection

A review of previous research on the Fergus was completed to aid site selection. From this examination the lakes were grouped into their different trophic categories according OECD (1982) guidelines. The OECD trophic classification system (Table 3.1) is based on TP, chlorophyll-*a* and secchi transparency (OECD, 1982). A revised version of this system has been used by the EPA using maximum chlorophyll-*a* values (Irvine *et al*., 2001). The WFD also recommends the use of TP, chlorophyll-*a* and secchi measurements but it also requires the inclusion of biological examination in order to classify lakes (European Union, 2000).

Since 1976 a number of projects have focused on investigating water quality in lakes along the river Fergus. Some of these have just looked at a single lake (Foged, 1977; Pybus *et al*., 1999 & 2001) or a small number of lakes (Allott, 1986) whilst others have been national projects that have included a small number of lakes from the Fergus catchment as well as lakes from other Irish catchments (Bowman *et al*., 1996

& 1998; Lucey *et al*., 1999; Irvine *et al*., 2001; McGarrigle *et al*., 2002; DeNicola *et al*., 2004; Wemaëre, 2005).

According to the EPA there are about 210 lakes within the Fergus catchment, but only 59 of these lakes have names associated with them. Wemaëre (2005) examined the chemistry of 20 of these 59 lakes. This study provided the most recent information on the largest amount of Fergus lakes, thereby acting as the most comprehensive and recent representation of lake chemical status. Wemaëre's (2005) study therefore played a primary role in the site selection whilst the other studies provided additional information.

Table 3.1 Trophic classification schemes for lake waters (OECD, 1982)

Lake category	**TP (µg/L)**	**Chlorophyll (µg/L) Mean**	**Chlorophyll (µg/L) Max**	**Transparency (m) Min**	**Transparency (m) Min**
Ultraoligotrophic	<4	<1.0	<2.5	>12	>6
Oligotrophic	<10	<2.5	<8.0	>6	>3
Mesotrophic	10-35	2.5-8	8-25	6-3	3-1.5
Eutrophic	35-100	8-25	25-75	3-1.5	1.5-0.7
Hypereutrophic	>100	>25	>75	<1.5	<0.7

Table 3.2 separates 16 Fergus lakes into different trophic classes according to chlorophyll-*a*. The lakes are either oligotrophic or mesotrophic and no lake is classed eutrophic. According to classification by TP (Table 3.3) four of the 16 potential study lakes are classed as oligotrophic, nine mesotrophic and three are eutrophic. Loughs George, Cullaun and Ballycullinan are close to the trophic class boundaries and could change trophic class if a slight change in nutrient input occurred, it is for this reason that discrete classification systems can be criticised. For example Atedaun is deemed oligotrophic according to chlorophyll-*a* and eutrophic according to TP. As the current project is interested in examining spatial and temporal algal assemblages and TP is recognised as one of the main influences on algal distribution and growth, the TP classification was given priority.

Table 3.2 Classification of lakes into trophic groups according to chlorophyll-*a* (measured chlorophyll-*a* in brackets, based on high and medium frequency sampling) (Wemaëre, 2005)

Oligotrophic (**0-8 μg l^{-1}**)	**Mesotrophic** (**8-25 μg l^{-1}**)	**Eutrophic** (**25-75 μg l^{-1}**)
Muckanagh (4.1)	Ballyteige (9.0)	
Bunny (3.3)	Dromore (9.0)	
O'Brien's (3.3)	George (10.3)	
Ballyeighter (3.6)	Castle (15.9)	
Girroga (4.9)	Ballyalla (8.1)	
Inchiquin (4.4)	Inchcronan (16.0)	
Atedaun (5.8)		
Cullaun (4.3)		
Ballycullinan (7.3)		
Keogh (4.1)		

Table 3.3 Classification of lakes into trophic groups according to TP (measured TP in brackets, based on high and medium frequency sampling) (Wemaëre, 2005)

Oligotrophic (**0-10 μg l^{-1}**)	**Mesotrophic** (**10-35 μg l^{-1}**)	**Eutrophic** (**35-100 μg l^{-1}**)
Bunny (5.5)	Ballyeighter (13.1)	Atedaun (36.7)
Girroga (8.2)	O' Briens Big (13.1)	Ballyteige (39.8)
Muckanagh (1.5)	Inchiquin (19.7)	Keagh (41.3)
George (9.3)	Dromore (20.8)	
Cullaun (8.8)	Ballyalla (21)	
	Castle (27)	
	Inchcronan (23.9)	
	Ballycullinan (34.9)	

A total of three lakes, one from each trophic class were selected for detailed examination and comparison. Loughs Cullaun, Inchiquin and Atedaun, located in the Ballyteigue subcatchment were selected for study following further consultation with the EPA (J. Bowman) and Norman Allott (TCD). Wemaëre (2005) found that Cullaun was oligotrophic, Inchiquin mesotrophic and Atedaun slightly eutrophic according to TP levels while chlorophyll-*a* values suggested that all three lakes were in mesotrophic state (Wemaëre, 2005).

National grid references and lake characteristics for each of the study lakes are shown in the Table 3.4 and Figure 3.2 shows their location relative to Ennis, Co. Clare. Lough Inchiquin is the most westerly of the three lakes. Lough Atedaun is situated to the south east of Lough Inchiquin. Lough Cullaun, to the north-east and is situated on the edge of the Burren plateau. Lough Cullaun feeds into Lough Atedaun via a series of streams and underground connections. The three lakes are located in the Ballyteige subcatchment which is a part of the larger Fergus catchment.

Table 3.4 Study lake characteristics (compiled in this study and from Wemaëre, 2005)

	Atedaun	**Cullaun**	**Inchiquin**
National Grid Reference	R297885	R316906	R268897
Latitude	52º56'34"	52º57'43"	52º57'11"
Longitude	09º02'45"	09º01'05"	09º05'21"
EPA lake code	27-00158-0980-000	27-00158-1190-000	27-00158-1320-000
Subcatchment	Ballyteige	Ballyteige	Ballyteige
Altitude (m)	22	25	35
Lake catchment area (km^2)	282.5	81.31	147.13
Lake surface area (km^2)	0.38	0.497	1.069
Mean Depth (m)	2.3	8.5	11.0
Maximum depth (m)	12	26	32
TP ($\mu g\ l^{-1}$)	11	20	36.7
Chl-*a* ($\mu g\ l^{-1}$)	4.3	4.4	5.8

Inchiquin's water chemistry has been examined on at least five occasions (Flanagan & Toner, 1975; Allott 1986 & 1990; Wemaëre, 2002 & 2005) and its phytoplankton examined on three occasions (Allott 1986; Irvine *et al.,* 2001). Atedaun's water chemistry has been analysed on at least four occasions (Wemaëre, 2005; Irvine *et al.*, 2001; De Nicola *et al*., 2003 & 2004) and phytoplankton populations have been examined on two occasions (Irvine *et al* 2001; De Nicola, 2004). Cullaun's water chemistry and phytoplankton populations have been examined on three occasions (Flanagan & Toner, 1976; Allott 1986; Irvine *et al.,* 2001). No study to-date has examined the physical, chemical and biological (algae) properties of each of these lakes in detail i.e. over an annual cycle.

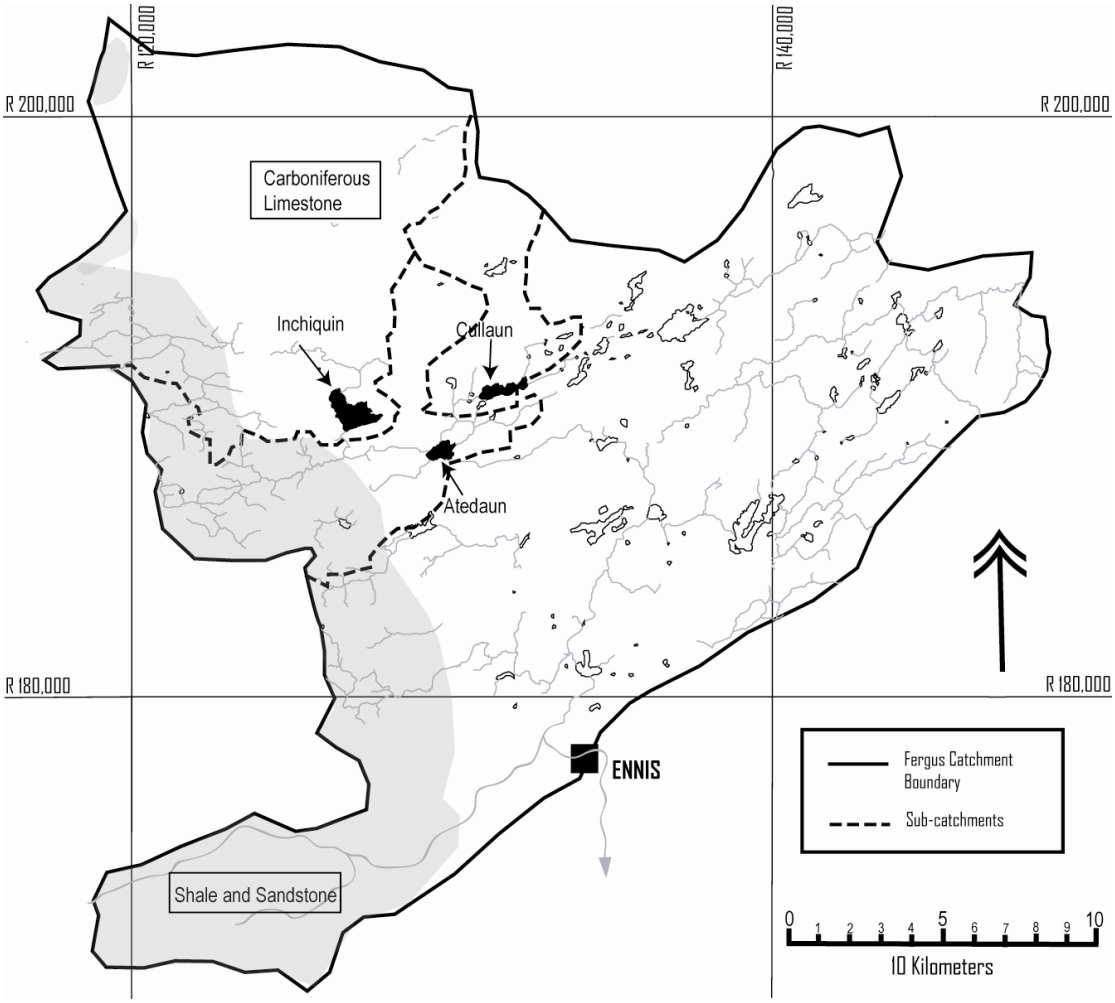


Figure 3.2 Study lakes Loughs Inchiquin, Cullaun and Atedaun

Biological quality records on the river Fergus date back to 1971 and are a result of sampling programmes by Clare Co. Council, An Foras Forbatha, Department of the Environment, the EPA and academic institutions. The river has been sampled at seven different locations, three of which are located upstream of the lakes within this study. Biological Q ratings from 1971 to 2001 from these EPA sampling stations (Clabby *et al.*, 2001) (see Table 3.5).

There has been reasonable consistency in quality values found at the sampling stations over the past thirty years. In 1996 there was a marked deterioration in water quality below Lough Atedaun, but water quality improved again and remained satisfactory to Ennis and beyond (Clabby *et al*., 2001). In 2001 the river at Poplar Bridge (0100) upstream of Lough Inchiquin was assessed as being slightly polluted but downstream from Inchiquin (0200) and at Corofin village (0300) it continued to be in a satisfactory condition. These general ratings (on a three yearly basis) lack specific

insights into what is occurring at these sites and may hide important seasonal or annual events within the river.

Table 3.5 Biological Quality Ratings (Q values) over a thirty-year period taken from sampling stations located along the upper parts of the Fergus River (Adapted from Clabby *et al.*, 2001)

EPA Sampling station	1971	1975	1979	1982	1985	1988	1991	1996	1998	2001
0100			4	4-5	4-5	4	4	3-4	4	3-4
0200	5	5	4	4	4	4	4	4	4	4
0300			3-4	4	4	4	4	3-4	4-5	4

3.2.1 Lough Atedaun

Lough Atedaun has the largest catchment (282.5 km^2) of the three study lakes but it has the smallest surface area (0.38 km^2) (Wemaëre, 2005). Bathymetry maps for each lake were created for this study: the bathymetry for Lough Atedaun is shown in Figure 3.3 with the main hydrological characteristics detailed in Table 3.4. The majority of the lake consists of a shallow area less than two meters in depth with a single basin with a maximum depth of between 9-12 metres (Allott, 1990). Measurements in this study indicated an average depth of 2.3m and a maximum depth of 12m. Wemaëre (2005) found that Lough Atedaun had the highest flushing rate of the 20 lakes in her study (450.6 flushings per year), twice the amount of the lake with the second highest number of flushings (Lough Ballyteige 258 flushings per year). Because of the shallow water depth, high flushing rates and exposed location it was assumed that Atedaun does not stratify during warmer periods. There are no reed beds surrounding the lake though submerged macrophytes occur in many places and fill the shallow areas during warmer periods. Much of the surrounding area is prone to flooding during the wet winter months and is used as farmland during drier periods. The land surrounding Lough Atedaun is used for agriculture with 49% being used for pasture farming and the remainder supporting mixed agricultural practices (Wemaëre, 2005).

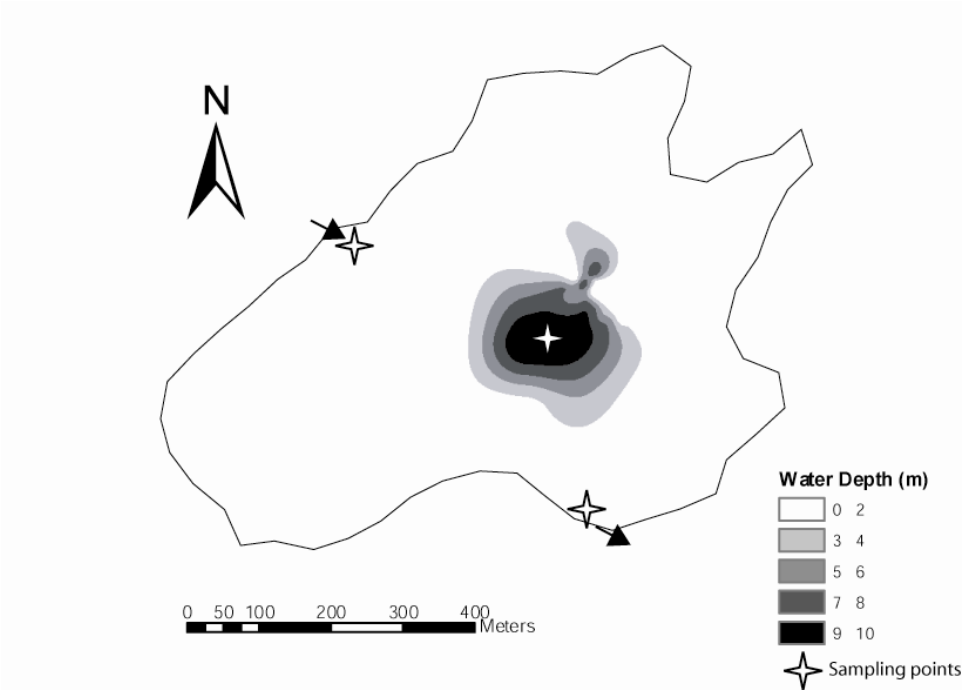


Figure 3.3 Bathymetry map of Lough Atedaun

3.2.2 Lough Cullaun

Lough Cullaun has the smallest catchment area of the three lakes, with an estimated catchment area of 81.31 km^2 and a lake area of 0.497 km^2 (Wemaëre, 2005). Lough Cullaun has a mean depth of 8.5m and a maximum depth of 26m (Wemaëre, 2005). Lough Cullaun has an elongated shape with no major bays or inlets. Lough Cullaun's shoreline is 4597 m in length with much of the shallow areas filled with reed beds. The reed beds are heavily concentrated around the east and west of the lake with the northerly shoreline composed of large rocks. Depth readings from the shore indicate a sharp descent and three deep basins each >20 metres in depth form its central axis (Figure 3.4). The land surrounding Lough Cullaun is used for agriculture (54% for pasture and the remainder mixed agriculture) (Wemaëre, 2005). The hydrology of Lough Cullaun has been examined in previous studies (Allott 1986 & 1990; Free 2002; Wemaëre, 2005). Groundwater drainage networks were found to be important in the catchment and the lake tends stratify in warmer months especially during summer.

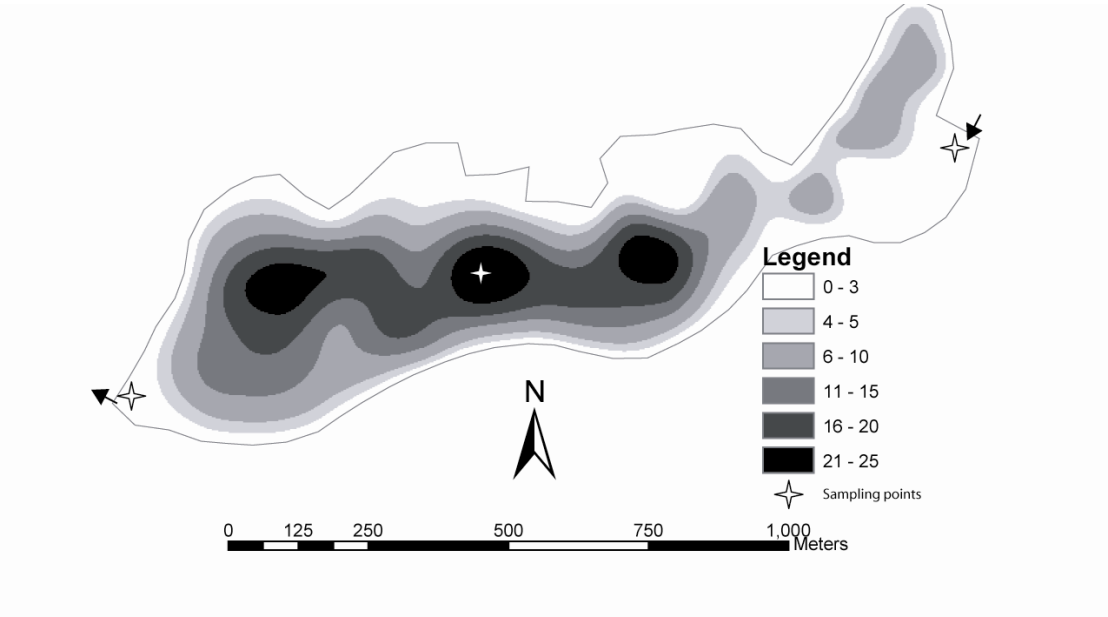


Figure 3.4 Bathymetry map of Lough Cullaun

3.2.3 Lough Inchiquin

Lough Inchiquin has an estimated catchment area of 147.13 km^2 (Wemaëre, 2005). It is the largest of the three study lakes with an area of 1.069 km^2. Lough Inchiquin has a mean depth of 11m, a mean depth of 32m and a shoreline 6365m in length (Wemaëre, 2005). The shoreline shelves steadily towards a deep central basin (Figure 3.5). The Fergus enters the lake in the northern most tip of the lake. The inflow area is a shallow area with a water depth of approximately 2m that is filled with macrophytes of the *Chara* species during summer months. Reed beds cover the eastern part of the lake while some of the lake is bordered by farmland. The lake itself is sheltered from the southwest by the tree covered Clifden hills (altitude 190 m). The land surrounding Lough Inchiquin is agricultural land with 40% classed as pasture (Wemaëre, 2005).

Lough Inchiquin has been the most extensively studied of any of the Clare lakes with sampling programmes going back to the 1970s (e.g. Flanagan & Toner, 1975). Lough Inchiquin is important as it is water source for the town of Corofin and also due to it popularity for angling tourism. Brown trout populations within Lough Inchiquin attract locals and tourists and have also lead to the scientific study of local fish populations and the periodic monitoring of water quality by the Central Fisheries Board (Allott, 1990). Recently the lake has been attracting attention because of algal blooms during summer months (Wemaëre, 2005).

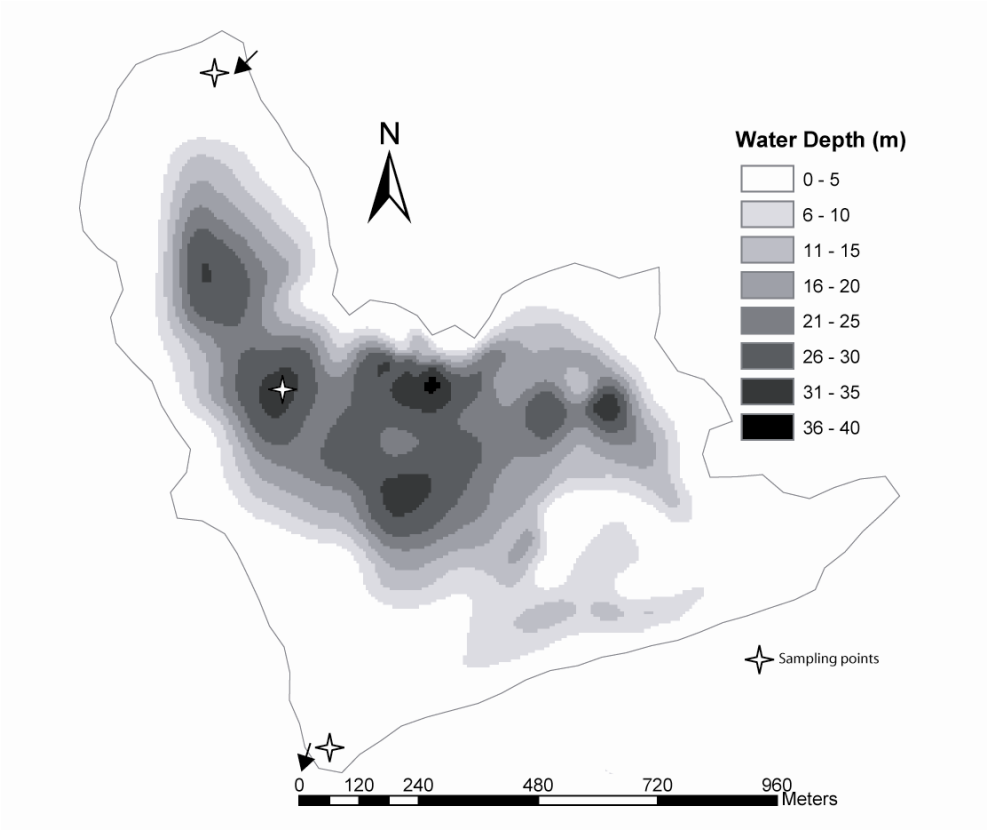


Figure 3.5 Bathymetry map of Lough Inchiquin

Chapter 4

Methods

This chapter describes the methodologies used in this project. The procedures involved in field sampling, sample collection, laboratory analysis, enumeration and data analysis are outlined.

4.1 Sampling Sites within lakes

Sampling of the three study lakes (Atedaun, Cullaun and Inchiquin) was conducted to enable assessment of phyisco-chemical and biological (algal) characteristics. Sampling consisted of the monthly collection of three samples per lake (a deep open water sample (for phytoplankton & water chemistry), an outflow sample (for phytoplankton only) and a littoral sample (periphyton only) between November 2004 and October 2005. The open water sample was collected from the lake water surface (<5 m) over the deepest point on the lake. Littoral samples were collected from stone substrata for phytobenthos. These samples were collected within littoral areas which may be influential on the lakes ecology such as inlets, or extensive shore areas (APHA, 1998).

In Lough Atedaun the inflow site had an average water depth of 1m; this site is about 40 metres away from the actual inflow in an area with a rich abundance of submerged macrophytes (see Figure 3.3). The outflow sample was also collected in 1 m water depth (although this varied considerably every month) in an area close to the shore area where there is a high abundance of submerged rocks with very little submerged macrophytes. The water flow was generally less turbulent than the inflow. The open water site is located above the deepest point (c. 9-12 m) in an exposed part of the lake. In Lough Cullaun both the inflow and outflow are located at opposite ends of the lake, near areas that have dense reeds and are relatively deep and calm (Figure 3.4). Average water depth here was around 1.5 metres with a high abundance of submerged macrophytes especially in summer. The open water site is located above the deepest point (c. 26 m) c. 400 metres away from the point of inflow and not under direct influence from the inflowing river. In Lough Inchiquin the outflow site was on average about 3 metres in depth and located near to a long area of shoreline with abundant submerged rocks (Figure 3.5). The depth at the deepest point was c. 32m in an open and exposed location on the lake. The inflow site had an average depth of 1 - 2 metres with many submerged macrophytes.

4.2 Sampling Frequency

The European Union Water Framework Directive make recommendations on the minimum requirements in a sampling programme; e.g. 6-months for phytoplankton; 1 month for hydrological paramaters (see Table 4.1) (European Union, 2000). It was decided that samples would be collected on a monthly basis over a one year period in this project to account for monthly and seasonal changes within the algal communities in response to physical and chemical change.

Table 4.1 Minimum sampling frequencies (European Union, 2000: WFD)

Biological	Phytoplankton	6 months
Hydro-morphological	Continuity	6 years
	Hydrology	1 month
	Morphology	6 years
	General	3 months
	Priority substances	1 month

Unfavourable weather conditions in January and June 2005 prevented boat access to the lakes. Water samples for these months were collected from the shore area as close as possible to the lake outflow. Periphyton samples were not included initially in the project, however, following a review of the literature it was decided to include periphyton to augment the study. Periphyton sampling commenced several weeks into the sampling programme therefore data exists only from sampling month 3 (January, 2005) onwards.

4.3 Field Work

On arrival at each lake, a field station was set up where equipment was organised. A field assessment sheet was completed on arrival at each lake, recording weather conditions, time of arrival etc. A handheld GPS (Garmin E-trex Summit) was used for navigation purposes and geo-locating the sampling sites. Lake water depths were recorded using a Speedtech SM-5 Depthmate portable sounder. Using G.I.S (Arc INFO 8.0) detailed maps of the lakes bathymetry were produced.

Monthly measurements of secchi transparency were made from a boat positioned over the deepest point in each lake. Water temperature was recorded in the top 0.5 m of the epilimnion at the time of sampling. A proxy measurement for water level was used in the project to estimate fluctuating lake water levels over the annual cycle. Water levels were recorded by measuring the distance between the top of the permanent slipway at each lake and the high water mark each month.

4.4 Sample Collection

As each sample was collected it was marked with the location, site, date and time. A student water sampler, which is a replica of a Van Dorn sampler, was used to collect water samples for chemical analysis and phytoplankton samples. The sampler is a weighted bottle with a stopper and drawstring on a graduated cable that is lowered to the required depth and filled. The advantage of this method is that it allows you to sample from differing water depths and both chemical and biological data can be produced from this sample.

The water sampler was used to collect an integrated 2 litre water sample from surface waters (0-5 m integrated) for chemical analysis and a 1 litre sample from a depth of 0.5 m was also collected for algal examination. This was then brought to shore for sub-sampling. A 250 ml sub-sample was extracted and preserved with Lugol's solution. The remaining 750 ml (containing unpreserved algal samples) were treated carefully and stored in a refrigerator for a few days to prevent deterioration. The preserved samples were kept in a sealed box for transportation back to the laboratory. Preservatives are necessary if samples are to be stored prior to analysis. The most suitable phytoplankton preservative is Lugol's iodine solution, which can be used for most algal forms. Samples were preserved with Lugol's solution by adding 0.3 ml Lugol's solution to a 100 ml sample (completely filling the container) and samples were stored in the dark (APHA, 1998).

Samples of benthic algae were collected from stone substrata (epiphyton) at two sites in each of the lakes following methods outlined by the American Public Health Association

(APHA, 1988). Five different stones were collected at random from each site at a depth of approximately 0.5 m. Algae were removed using a brush or scalpel from an approximate 5x5 cm area. Samples were then placed in 50 ml vials containing lake water from the sample site, preserved with Lugol's and stored in a dark container at 4^{o} C awaiting identification.

4.5 Sample Analysis

The project researcher was responsible for the physical and biological analysis of data, whilst Dr. Norman Allott in Trinity College Dublin carried out the chemical laboratory work.

4.5.1 Chemical Analysis

Dr. Norman Allott, Trinity College Dublin undertook the water chemistry analysis in the laboratory of the Centre for the Environment. Samples for chemical analysis were collected from surface waters (0-5 m) above the deepest point in each lake. This resulted in 36 water chemistry samples. Chemical analysis for conductivity, pH, alkalinity, DMRP, TP and chlorophyll-*a* were conducted following the methods outlined in Table 4.2.

Table 4.2 Chemical parameters examined and method references

Chemical	Abbreviation	Measurement unit	Method
pH		Units	Davison (1990)
Total alkalinity	Alk	mg/l	Clesceri *et al.* (1989)
Dissolved Molybdate Reactive Phosphorus	DMRP	µg/l	Eisenreich *et al.* (1975)
Total Phosphorus	TP	µg/l	Eisenreich *et al.* (1975)
Chlorophyll-*a*	Chl-*a*	µg/l	Standing Committee of Analysts (1983)
Nitrate Nitrogen	NO_3-N	µg/l	Armstrong *et al.* (1967)
Conductivity	Cond.	µS/cm	

4.5.2 Biological Analysis

In the laboratory at Mary Immaculate College algal samples were prepared for analysis, so that species could be identified and counted. This involved concentrating samples, microscope examination of fresh and preserved samples and the identification and counting of the different algal species in each sample using a counting chamber (Wetzel & Likens 1991). John *et al.* (2002) outlines three different methods of concentrating phytoplankton samples; sedimentation, membrane concentration and centrifugation. Different projects use different methods; for instance Irvine *et al.* (2001) used sedimentation whilst King & Champ (2000) used a mixture of sedimentation and centrifugation. The current project concentrated samples using sedimentation, as it was the method which most suited the laboratory facilities available. Sedimentation is non-selective and non-destructive in comparison to filtration and centrifugation although many of the pico plankton, the smaller nanoplankton and actively swimming flagellates (in unpreserved samples) may not settle completely.

The sedimentation method used followed guidelines set out by the APHA (1998). A 50 ml sub-sample was taken from the 250 ml preserved sample from the field. One hour of settling time is recommended per 1 mm of column depth. The iodine in the Lugol's solution kills, preserves and stains the algae and the acetic acid prevents the loss of flagella; this treatment also makes the algae heavier so their rate of sinking is increased (John *et al.*, 2002). Containers were moved carefully in order to avoid any non-random distribution of the settled matter.

A Meiji 2002 compound microscope was used to examine all algal samples. Prior to counting, smears of fresh algal samples were examined at x400 magnification in order to aid identification. Samples were counted in a Sedgwick Rafter counting chamber. The maximum ocular that can be used with the Sedgwick Rafter is x200 magnification. A Nikon digital camera attached to the microscope was used to take photographs of the different species. Attempts to quantify the phytobenthos samples within the Sedgwick

Rafter counting chamber were made but samples were too concentrated thus preventing quantitative enumeration. Samples smears were subsequently examined qualitatively at x400 magnification.

The microscope was calibrated against a known scale since every instrument differs in magnification depending on the combination of oculars and objectives. A Whipple grid (was placed in the eyepiece of the microscope and a standardised stage micrometer on a glass slide was used (APHA, 1998). Methods for calibration detailed by both APHA (1998) and Wetzel (2001) were followed within this study. The main algal taxonomic guide used was John *et al.* (2002) accompanied by the electronic identification keys on CD-Rom (green and blue green algae). Identification of diatoms from live counts was made using Bourelly (1966, 1968 & 1986), Cox (1996) and John *et al.* (2002). The author also underwent a week long training course in the University of Durham in algal identification and taxonomy under the guidance of Dr. David John, Prof. Brian Whitton and Prof Alan Brook. Problematic samples were also sent to Prof. Brian Whitton for confirmation of the identification.

4.5.2.1 Biovolume Estimation

Biovolume is important in the study of algal ecology providing information on species physiology and ecology. Many different programmes have been developed in order to calculate cell biovolume (e.g. Kirschtel (1992) and Sun & Liu (2003)). This project used Sun & Liu's (2003) biovolume programme as it was better suited to estimating biovolume calculations for algae from many different taxa.

Algal cells were measured in terms of width, length and breadth as well as any major physiological feature. As cells settle on the Sedgwick Rafter base plate, measurements were taken using the graticule, which was inserted in the microscope eyepiece. It is recommended that 20 or more individuals should be measured to avoid bias in the results (Hillebrand *et al.,* 1999; Sun & Liu, 2003). A minimum of ten measurements were taken for each of the phytoplankton identified in this study. More measurements were taken on

the more common algae and the mean of these measurements was then used for the calculation of the surface area and biovolume for each species.

Biovolume calculations are based upon using geometric models or shapes that are similar to the real shape of the organism. Problems can occur when choosing the correct model and in having the correct measurement for each part of the shape (algal cell) (Sun & Liu, 2003). Difficulties were encountered when trying to measure cell height in the counting chamber. This was overcome by estimating the height from the width of the cell, because the height of small algal cells is usually approximately equal to the width (Sun & Liu, 2003). The biovolume programme used in this project is based upon cell codes and shapes provided in Table 1 in Sun and Liu (2003) and Table 2 in Hillebrand *et al.* (1999). Estimated biovolume values were then multiplied by cell abundance values and this produced total biovolume values for each species which then enabled calculation of monthly biovolumes.

Due to the large number of species found and the large number of species with a small contribution to total biovolume values it was decided to reduce the original dataset. This is a standard practise and is recommended when using C2 (Ter Braak 1986, 1987; Juggins, 2003). The benefit of reducing datasets is that it removes many outlying species which would have very little influence on the spread of data within an ordination diagram (Juggins, 2003). It also allows studies to focus more on the more abundant species. Therefore species with a relative of $\leq$ 5% abundance on at least one occasion were removed from the data set.

4.6 Data analysis

The aim of statistical analysis is to condense data so that it may be described efficiently reducing the information to provide a succinct summary (Shaw, 2003). A number of computer programmes were used in the analysis of data produced from fieldwork in this project. Algal cell counts and chemical data were organised in Microsoft Excel. Basic statistical analysis and graphical illustration was also performed using Excel. The computer programme C2 (Version 1.3) Juggins (2003) was used to transform the

environmental variables, provide descriptive statistics and to create scatter plots. XLSTAT 2006 enabled decisions on the most appropriate transformation for each variable and was used to create Q-Q plots and histograms. Canoco 4.5 (Ter Braak and Šmilauer, 2002) was used for multivariate data analysis specifically Principal Components Analysis (PCA), Correspondence analysis (CA) and Canonical Correspondence analysis (CCA).

4.6.1 Exploratory data analysis

The physico-chemical variables used in this study were graphed in Microsoft Excel according to sample month. Frequency histograms were created in Excel using Sturges rule ($h = R\ (range)/K$ *where* $K = 1 + log_2 (n)$) to determine the number of ranges and the optima bin width in each histogram (Shaw, 2003). This created an overall impression of the distribution of data for each variable and Q-Q plots and scatter plots showed the distribution of results, allowed for the identification of any outliers and decisions on normalising the data using log transformation.

Phytoplankton data were initially examined in Microsoft Excel with the use of different ecological diversity indices. Species diversity or ecological diversity is a parameter of community structure involving species and their abundances for the taxa considered (Washington, 1982). The Shannon index (*H*), one of the most commonly used diversity indices, was used to measure diversity within algal samples (Washington, 1982) using the following equation:

$$H' = \frac{-\Sigma Pi * \log_{10}(Pi)}{\log_{10}(2)}$$

H' values represent the frequency of species within a sample, reflecting both the number of species and their relative proportion. Additionally, equitability or evenness was calculated and represents the evenness of species within a sample. Evenness was calculated as follows:

$$E = \frac{H'}{H\ Max} = \frac{-\Sigma Pi * \log_{10}(Pi)}{\log (S)}$$

Eveness near zero suggests that the community to be dominated by one species, while a value near 1.0 shows it to have an equal balance between all species (Shaw, 2003).

4.6.2 Missing data and data transformation

Missing data are a feature of many ecological studies and can be a result of several factors ranging from poor weather conditions to loss of samples to changing methodologies. Missing physico-chemical variables were replaced in this project with the mean of the remaining data as recommended by Lepš & Šmilauer (2003). Species data were converted into relative (%) abundances and then square root transformed prior to multivariate analysis. Transforming environmental data reduces the influence of extreme values (outliers) and provides a more normal distribution to each variable. To determine which transformation was best (log or square root), Q-Q plots were created for each variable. In a Q-Q plot the relationship between the distribution of a variable and its theoretical distribution are graphed. The transformation with the closest distribution to a normal distribution according to the Q-Q plot was chosen. The addition of one (+1) to any data values equal to or below zero was used as negative values cannot be used in ordinations.

4.6.3 Multivariate data analysis

Multivariate statistics involves three or more environmental variables; these numerical functions usually describe patterns or relationships between many variables. Multivariate analysis based upon ordination techniques aims to recover the underlying structure in a data matrix. In multivariate analysis the relationship between multiple variables and/or species are explored, with ordination plots providing a view which best describes these multiple correlations at work (Ter Braak, 1987). Multivariate analysis is based on either indirect gradient analysis or direct gradient analysis with gradient analysis describing any method, which seeks to relate species data to environmental variables (Lepš & Šmilauer, 2003). Indirect gradient analysis seeks to describe the inherent distribution of samples or species as a result of the measured environmental variables. Direct gradient analysis is used when one wishes to test the influence of one data set (environmental variables)

directly upon another (species responses). The position of species and samples within the ordination are constrained by the influence of the environmental variables with similar species and sites being located near to each other and to the variables with the greatest degree of influence.

In this project Principals Components Analysis (PCA) was used to investigate the distribution of samples based on the measured environmental variables. The intention of using PCD is to simplify data by reducing it to a number of important axes of variation (Lepš & Šmilauer, 2003). Ordination analysis produces eigenvalues which represent the degree of variation exhibited by each axis. PCA an indirect (unconstrained ordination) technique in which the first principal axis will run through the mean of the data set. PCA cannot cope with missing values hence the use of mean values to replace missing data. Data were log transformed prior to using PCA analysis. PCA is commonly displayed in a biplot where sampling sites are symbolised by points and variables are represented by arrows. Points close to one another can generally be interpreted as being similar in composition. Points near to the mean centre (0, 0 centroid) show little deviation from the mean whilst samples located far from the centre deviate greatly from the mean. The arrows point in the direction of the maximum rate of change with angles between arrows representing their degree of correlation and the length of arrows represent the degree of influence over the distribution of samples (Ter Braak, 1986).

Before analysis of the relationship between the environmental variables and the algal assemblage was carried out it was necessary to decide whether to use a linear or unimodal approach. Therefore it was necessary to estimate the degree of heterogeneity within the algal assemblages. This is done using Detrended Correspondence Analysis (DCA) which can measure the beta diversity in community composition (Lepš & Šmilauer, 2003). A linear approach is most appropriate if the length of the longest gradient is less than 3 whilst a unimodal approach is more appropriate if the length of the longest gradient is greater than 3. PCA is the recommended linear method while Correspondence Analysis (CA) is the recommended unimodal method (Lepš & Šmilauer, 2003).

CA was used to examine the distribution of the biological data, with sample scores been based on the location of species scores. This approach allows for an internal examination of the algal assemblage (Shaw, 2003). Correspondence analysis (CA) is comparable to PCA in its utility for data interpretation and has the virtue that sites and dependant variables are ordinated at the same time, facilitating the production of a biplot (Lepš & Šmilauer, 2003). CA is based upon weighted mean values; sites which are weighted by dependent variables and dependant variables by sites (Ter Braak 1986). As with PCA samples and species located close to one another share similar traits.

Canonical Correspondence Analysis (CCA) aims to understand the relationship between community composition and environmental factors and test the influence of one data set upon another (Lepš & Šmilauer, 2003). CCA uses the same basic algorithm as CA but the ordination is constrained (Ter Braak, 1986). A CCA ordination diagram shows the main pattern of community composition as accounted for by the environmental variables, and also shows the distribution of species along each environmental variable (Ter Braak, 1986). Monte Carlo permutation tests can be carried out to test the significance of each ordination axis and thus the relationship between the environmental variables and species composition.

Chapter 5

Environmental Variables

In this chapter the results of the 12 measured environmental variables are detailed along with the sampling frequency of each variable and missing data is described.

5.1 Hydrological and physical variables

Rainfall data were downloaded from the Met Eireann station in Claremorris (40 km northwest of the study area) (Figure 5.1). Maximum rainfall was recorded in January 2005 (123.4 mm) and minimum rainfall was recorded in February 2005 (45 mm). Rainfall values increased through March, April and May but decreased through June and July (44 mm) and began to increase again from August onwards.

Water temperature, secchi transparency and water level variation were measured on a monthly basis at all three lake sites. Water temperatures in each lake followed a similar pattern as shown in Figure 5.2. Lowest water temperatures occurred in February and March with temperatures of 6 and 7 °C. Highest temperatures occurred in June and July with temperatures of 20 and 21°C. Mean and median values for each of the three lakes were 9°C.

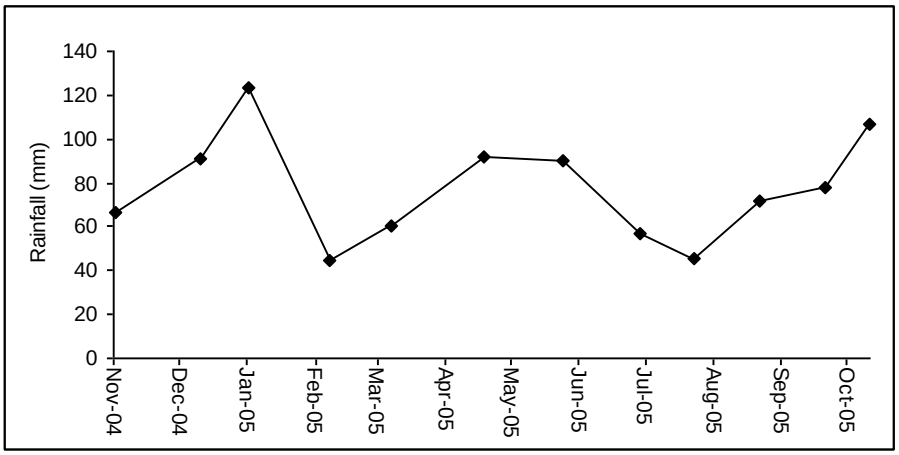


Figure 5.1 Monthly rainfall (mm) recorded at Claremorris from November 2004 to October 2005 (Met Eireann)

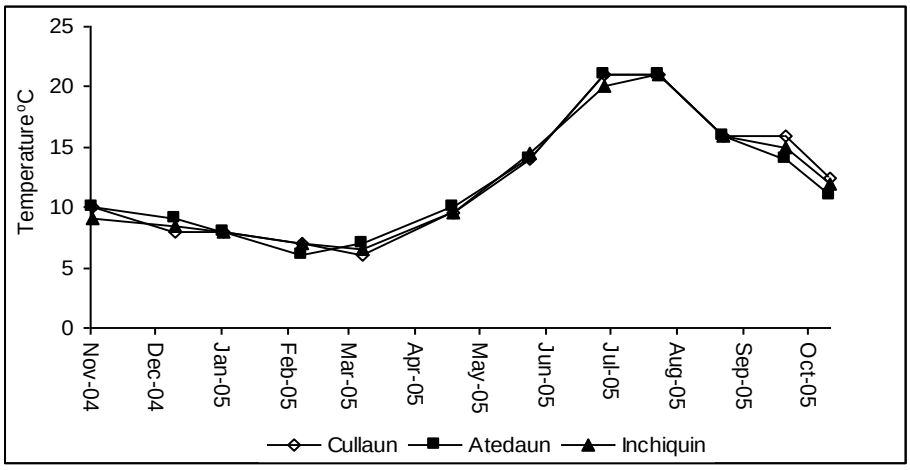


Figure 5.2 Monthly water temperature (^{o}C) for Lough's Atedaun, Cullaun and Inchiquin (data for January, June and July are from shore samples)

Water level variation was recorded for 10 months commencing in January 2005. This proxy water level estimate provided valuable information in respect of changing water levels in each of the three lakes. These trends are shown in Figure 5.3. Water level varied the least in Lough Cullaun. Highest levels were found in January and they decreased through to August but there was little variation between months. Water levels in Lough Inchiquin reached their highest in January and August and their lowest during the summer months. Lough Atedaun shows the greatest amount of variation with water levels changing considerably between months. In all three lakes the highest water level occurred in January when water levels were almost at the top of the boat slipway in each lake. April and September also had high water levels. Lowest water levels occurred in March and from May to July when there was the greatest distance between the top of the slipway and the water level in each lake. Seasonally Inchiquin and Atedaun follow a similar pattern but the degree of change between months is far greater in Lough Atedaun.

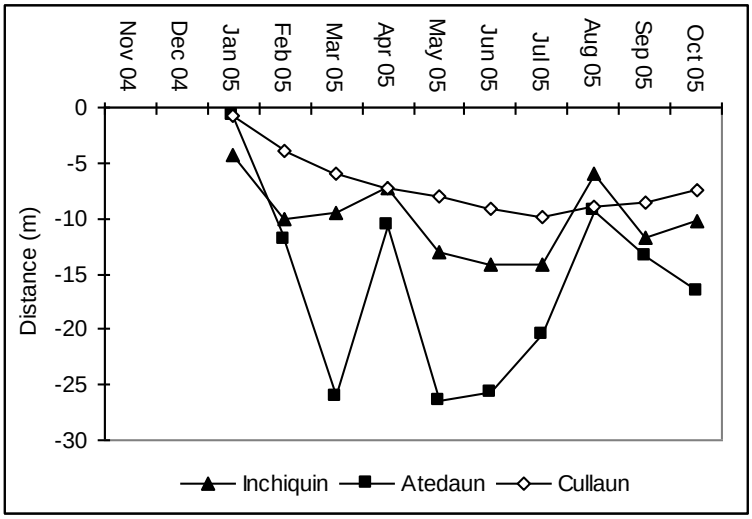


Figure 5.3 Water level variations at Lough's Atedaun, Cullaun and Inchiquin

Secchi depth values were recorded at the deepest points in each of the three lakes and are shown in Figure 5.4. Secchi values were not recorded in January and August due to poor weather conditions. Minimum transparency was recorded at Lough Inchiquin in December, April in Atedaun and March in Cullaun. Maximum transparency occurred in February at Inchiquin, September in Atedaun and May in Cullaun. The mean values for Inchiquin and Atedaun were similar at 2.39 m and 2.37 m but there was a considerable difference with Cullaun which had a mean value of 5.36 m.

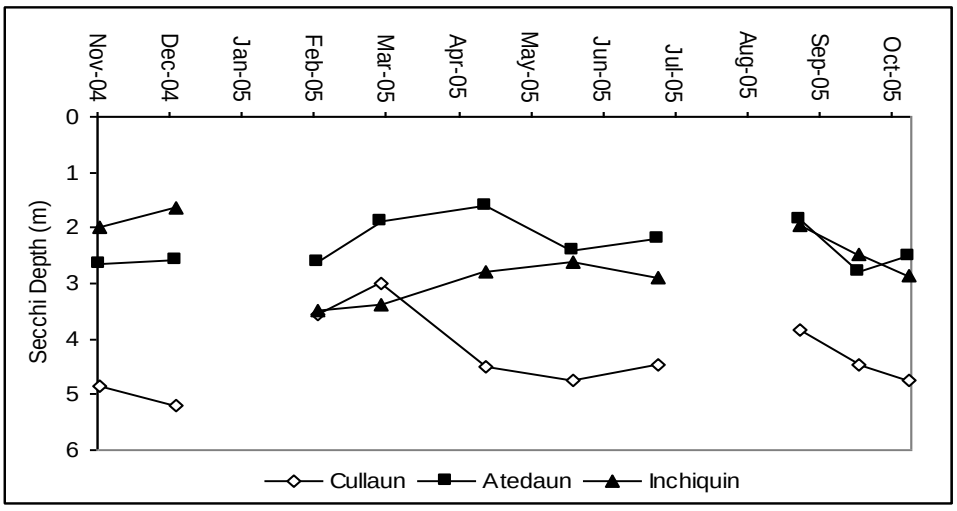


Figure 5.4 Secchi depths (m) for Lough's Atedaun, Cullaun and Inchiquin (no data for January, June and July 2005)

5.2 Chemical analysis

Water samples for chemical analysis were analysed on a monthly basis at Trinity College Dublin by Dr. Norman Allott. Total phosphorus (TP), dissolved molybdate reactive phosphorus (DMRP), nitrogen (NO_3-N), chlorophyll-*a* (Chl a), conductivity and alkalinity were examined. All tables and figures include data from 11 monthly samples for each lake; there is no data for January, as the sample was lost by the courier company. All samples were taken from surface open waters (and from the shore area in June and July due to poor weather conditions). No major difference was found in the annual values (mean, medium, minimum and maximum) when the shore samples were included.

5.2.1 Total Phosphorus

Inchiquin had a minimum TP value of 19µg/l in July and a maximum value of 45 µg/l in August; both the mean and median values were 34 µg/l (Table 5.4). Inchiquin's TP levels ranged from between 30µg/l and 45 µg/l for the months of November through to April (Figure 5.5). The onset of summer saw a reduction in TP values to the annual minimum of 19 µg/l. This trend has been well documented in Irish lakes with higher concentrations in winter and lower in summer (Irvine *et al.,* 2001). The general seasonal pattern is most likely caused by increased input of phosphorus from the catchment due to high amounts of rainfall during winter and increased loss of phosphorus to the sediment in winter (Clabby, 2001; Irvine et al., 2001; Free, 2002).

There is a higher degree of change in TP during the first five months (November to April) in Atedaun compared to Lough Inchiquin. In Lough Atedaun the TP concentration in December was more than double that for November. Levels reduced considerably in February and March and increased again in April. Values reduced again slightly from May through to July. August saw a rapid TP increase with a sharp decrease in September. Atedaun's mean value at 27 µg/l, is 7 µg/l less than Inchiquin. Cullaun's monthly TP shows the least amount of variability of the three lakes. As Figure 5.5 illustrates, Cullaun exhibits little difference between winter and summer TP values. The annual minimum TP value of 5 µg/l occurred in December, whilst the annual maximum TP value of 13 µg/l occurred in October. The annual mean value was 9 µg/l TP.

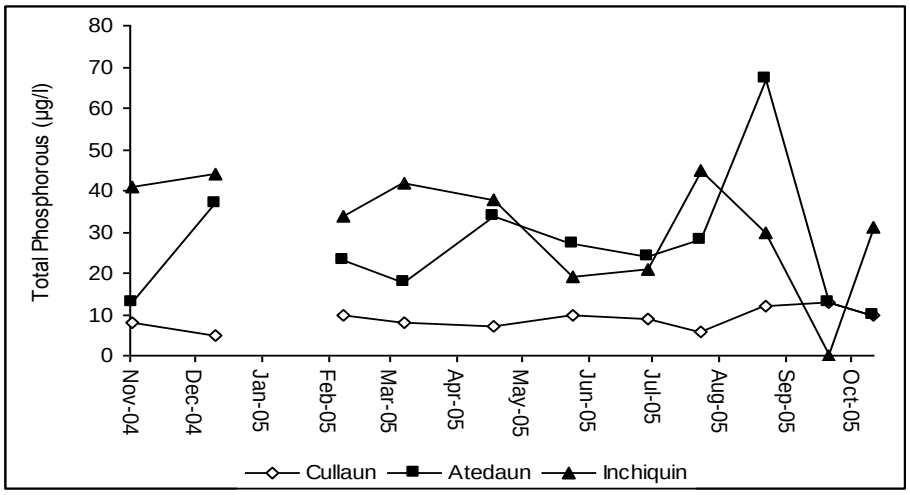


Figure 5.5 Monthly total phosphorus (TP) Lough's Atedaun, Cullaun and Inchiquin (no data for January 2005)

5.2.2 Dissolved molybdate reactive phosphorus (DMRP)

DMRP represents the phosphorus that is available for use by biological organisms in lakes. Figure 5.6 shows monthly variations in DMRP for the three lakes. Minimum values were similar for each of the three lakes whilst maximum values differed considerably. Each of the lakes followed a similar monthly and seasonal trend with highest values occurring in winter and lowest values occurring in summer. The annual maximum value occurred in February for each of the three lakes, whilst summer minimum values occurred in June and July.

5.2.3 Nitrogen (NO_3-N)

The lowest nitrogen values occurred in the summer months with July and August both having values of <100 µg/l NO_3-N. Maximum values occurred in March for each of the three lakes. Similar to phosphorus there were large differences between seasons with the highest NO_3-N concentrations found in winter and spring and the lowest in summer and autumn. As with TP and DMRP the reduction in values in late spring and summer is probably due to increased biological activity (Irvine *et al.*, 2001). This trend occurred in each lake. However, autumn increases were only apparent in Inchiquin. Inchiquin consistently had the highest values while Atedaun initially showed higher values than Cullaun but from January onwards both lakes showed similar results (Figure 5.7).

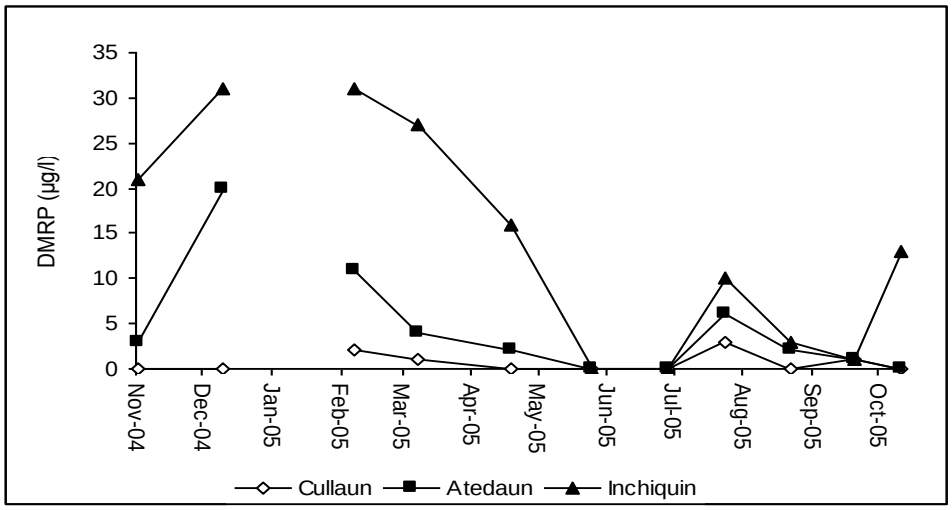


Figure 5.6 Monthly DMRP (µg/l) for Lough's Atedaun, Cullaun and Inchiquin (no data for January 2005)

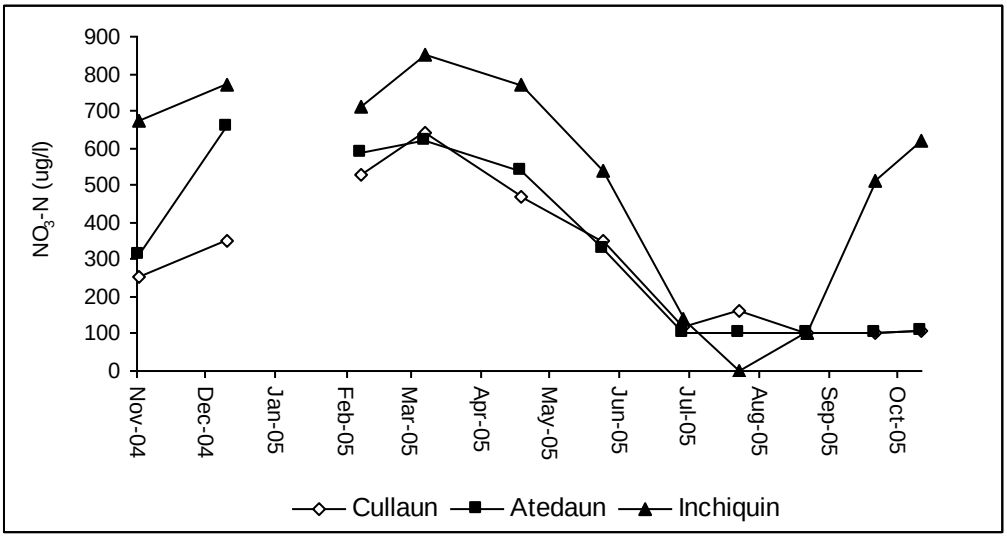


Figure 5.7 Monthly NO_3-N(µg/l) for Lough's Atedaun, Cullaun and Inchiquin (no data for January 2005)

5.2.4 Chlorophyll-*a*

Measurement of chlorophyll-*a* is a standard limnological monitoring parameter and is used as an index of phytoplankton standing biomass. Inchiquin had the highest annual average and Cullaun the lowest (Figure 5.8). The lowest chlorophyll-*a* value (0.10 µg/l) was found in Lough Cullaun in February and the maximum value (20.3 µg/l) in Lough Inchiquin in September. Winter months saw the lowest chlorophyll-*a* values for each of the study lakes and it was not until March that values began to increase. In Lough Cullaun chlorophyll-*a* values were < 5 µg/l until August at which point they

increased to their annual maximum value of 9.4 µg/l before reducing again in the high autumn. In contrast to this Atedaun reached its annual maximum value of 10 µg/l chlorophyll-*a* in the month of April. Chlorophyll-*a* reduced in May, then slowly increased until September and decreased again in October. Inchiquin's values increased from February to May then decreased from May to July and increased sharply from July (4 µg/l) until September (20 µg/l). Concentrations decreased substantially between September (20 µg/l) and October (3 µg/l).

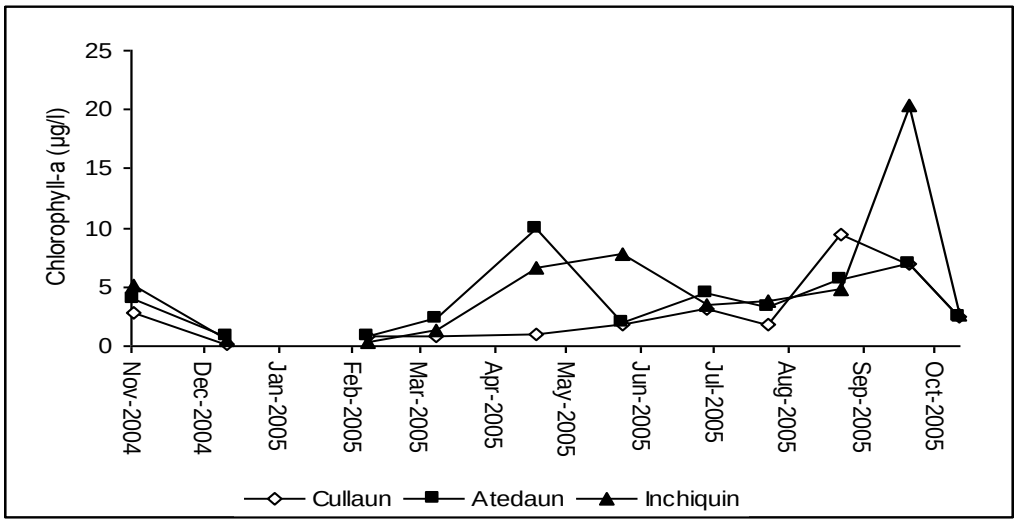


Figure 5.8 Monthly Chlorophyll-*a* (µg/l) for Lough's Atedaun, Cullaun and Inchiquin (no data for January 2005)

5.2.5 pH

pH values were in a similar range for all three lakes, with a minimum value of 7.75 and a maximum value of 8.45 (Figure 5.9). An increasing trend in pH was apparent over the annual cycle from winter through to summer/autumn for each study lake.

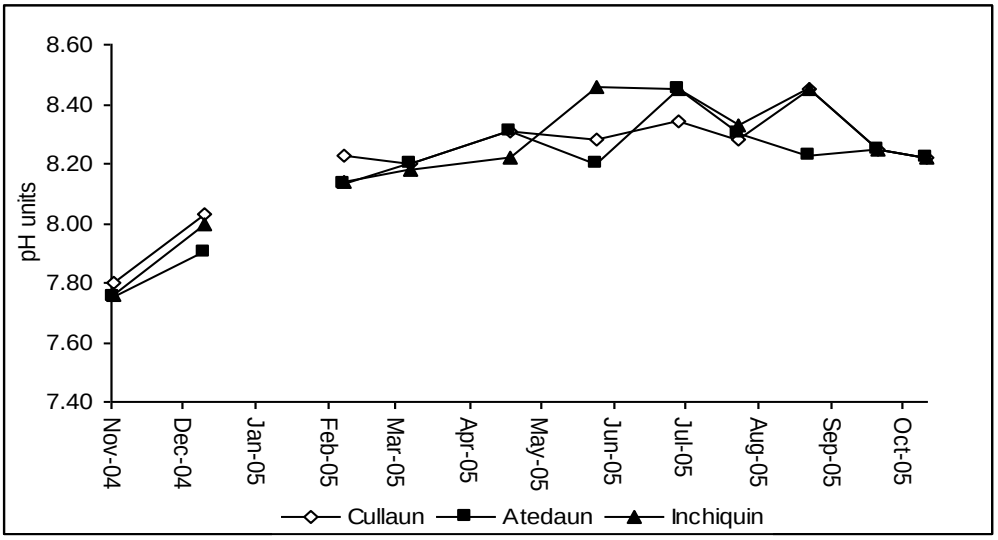
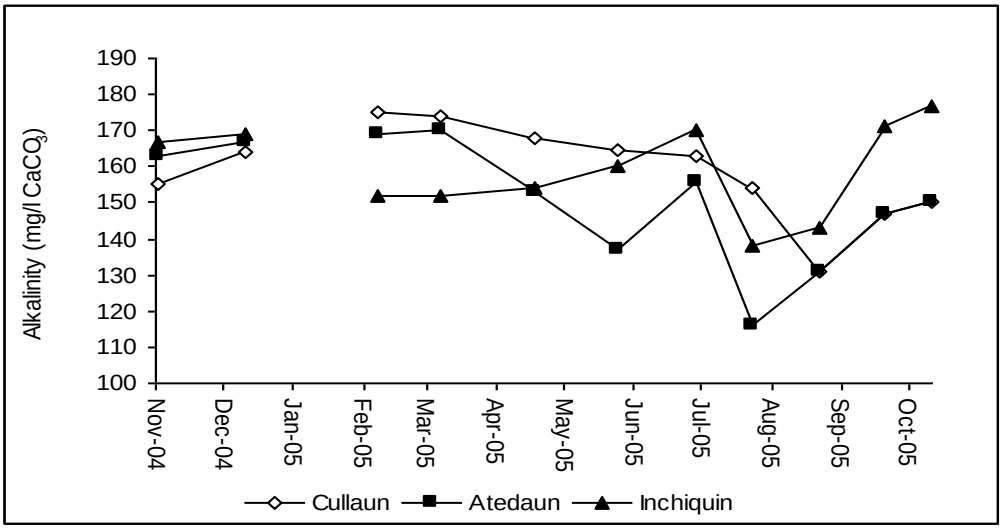


Figure 5.9 Monthly pH values in Lough's Atedaun, Cullaun and Inchiquin (no data for January 2005)

5.2.6 Alkalinity ($CaCO_3$)

Alkalinity (mg/l $CaCO_3$) was similar for each of the lakes as was expected (Figure 5.10). Alkalinity values ranged from a minimum value of 131 mg/l $CaCO_3$ (in Cullaun and Atedaun) to a maximum value of 177 mg/l $CaCO_3$ in Lough Inchiquin. Similar trends occurred in each of the lakes with higher alkalinity recorded in winter months and lower alkalinity in summer.



F**igure 5.10** Monthly alkalinity (mg/l $CaCO_3$) in Lough's Atedaun, Cullaun and Inchiquin (no data for January 2005)

5.2.7 Conductivity

Conductivity is a measure of the ability of water to conduct an electrical current. Values range from a minimum of 317 µS/cm in Lough Atedaun to a maximum of 422 µS/cm in Lough Atedaun (Figure 5.11). Higher values occurred during colder months in each of the lakes, with values decreasing in warmer months Conductivity values increased in each lake during the autumn of 2005.

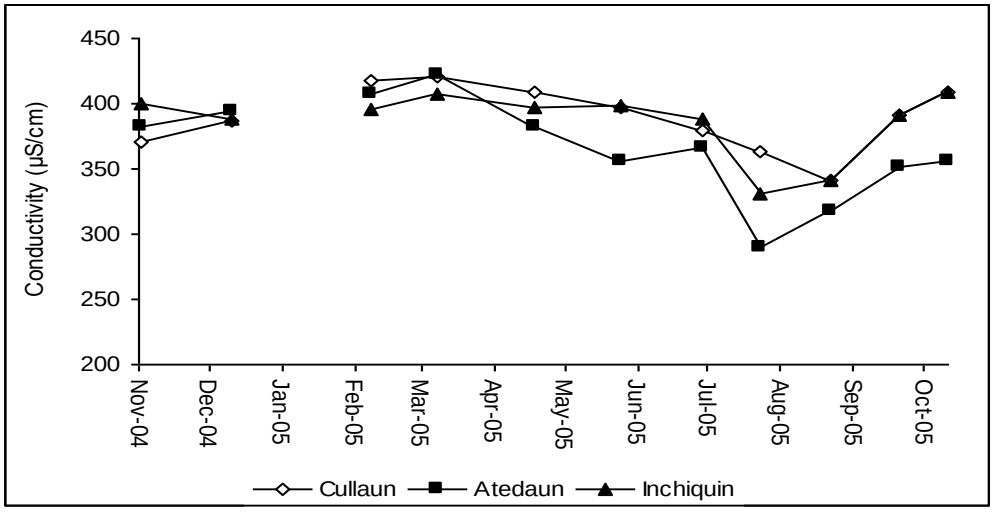


Figure 5.11 Monthly conductivity (µS/cm) for Lough's Atedaun, Cullaun and Inchiquin (no data for January 2005)

5.3 Trophic state

Trophic state classification for the study lakes is using (i) mean total phosphorus (TP) (ii) mean and (iii) maximum chlorophyll-*a*, and (iv) minimum and (v) maximum secchi transparency following OECD (1982) criteria (Table 5.1). When mean TP and mean and maximum chlorophyll-*a* are used to categorise the lakes then each of the lakes is assigned a mesotrophic status. When minimum transparency is used Cullaun remains in the mesotrophic category whilst Atedaun and Inchiquin move into the eutrophic category. When maximum transparency is used Cullaun is categorised as oligotrophic and Atedaun and Inchiquin are classified as being mesotrophic. The range of values for each OECD trophic category is quite broad; for example, mean TP values in the mesotrophic category range from 10-35 µg/l (see Table 3.1). In the current study Cullaun had an annual mean value of 9 µg/l TP and thus bordered on the

oligotrophic/mesotrophic categories. Mean TP in Atedaun (27 µg/l) confirms a highly mesotrophic state, whilst Inchiquin (annual mean 34 µg/l TP) borders on the meso-eutrophic categories. Mean TP values in the current study have increased in Cullaun (+2) and Inchiquin (+13.8) and decreased in Atedaun (-9.7) when compared to high and mid-high frequency samples collected by Wemaëre (2005). A similar pattern occurs when mean chlorophyll-*a* measurements are used; Cullaun borders on being oligotrophic, and Atedaun and Inchiquin are close to being eutrophic. Transparency values are clearly useful then as Atedaun and Inchiquin are assigned a eutrophic status and Cullaun is given an oligotrophic status. It is unrealistic therefore to categorise all the study lakes as mesotrophic. It is for this reason that discrete classification systems can be criticised as many lakes fall between two classes. A reclassification of the study lakes suggest that Lough Cullaun is oligo-mesotrophic, Atedaun is highly mesotrophic whilst Inchiquin is meso-eutrophic.

Table 5.1 Annual mean TP, chlorophyll-*a* and transparency from Loughs Atedaun, Cullaun and Inchiquin and their trophic classification (OECD, 1982)

Lake	TP µg/l (mean)	Chlorophyll µg/l (mean)	Chlorophyll µg/l (max.)	Transparency m (min.)	Transparency m (max.)
Atedaun	27	3.91	10	1.61	2.79
Cullaun	9	2.85	9.4	3.0	5.75
Inchiquin	34	5.15	20.3	1.62	3.5
Atedaun	Mesotrophic	Mesotrophic	Mesotrophic	Eutrophic	Mesotrophic
Cullaun	Oligotrophic	Mesotrophic	Mesotrophic	Mesotrophic	Oligotrophic
Inchiquin	Mesotrophic	Mesotrophic	Mesotrophic	Eutrophic	Mesotrophic

5.4 Acid status of lakes

The acid status is assigned to lakes based on average pH and alkalinity values as set out by the European Economic Commission (ECE). They have set out a classification system for ecological quality that includes five quality classes based on pH and alkalinity (Premazzi & Cardoso, 2000). The system is based on the toxicological impact of acidity on aquatic life as established in US-EPA practices. The three lakes in this study have similar pH and alkalinity values. When these values are categorised

according to EVCE categorisation each of the lakes is ranked as having a good buffering capacity according to alkalinity values and a good ecological status according to pH and alkalinity results.

5.5 Summary

Strong seasonal change was evident in the physico-chemical data. Higher rainfall occurred during winter and spring/summer. Water level variation and changes in lake water depth showed the greatest degree variation in Lough Atedaun. Surface water temperatures were similar in each lake with lowest temperatures in February/March and warmest temperatures between June and August. Water clarity was generally higher in Cullaun compared to Atedaun and Inchiquin. Little variation in pH, conductivity and alkalinity was evident between the three lakes. Seasonal change saw higher pH evident during summer concomittant with low conductivity and low alkalinity. Higher levels of TP and DMRP and NO^3 were evident in the lakewaters in autumn and winter . Levels decreased with the onset of summer and warmer temperatures when biological activity is reaching a maximum in most lakes. Inchiquin had the highest levels of DMRP and Cullaun the lowest. Chlorophyll-*a* was barely detectable in during winter and only began to increase in the study lakes from March onwards. High algal productivity was evident in Inchiquin. When OECD (1982) classification was applied to the results produced from this study Cullaun was re-assigned to an oligo-mesotrophic category, Atedaun retained a mesotrophic category and Inchiquin was assigned a meso-eutrophic category.

Chapter 6

The phytoplankton of Loughs Atedaun, Cullaun and Inchiquin

This chapter aims to examine phytoplankton diversity spatially and temporally within each of the lakes. The chapter has been divided up into several key areas. Firstly a general discussion of the different species found is presented in terms of species richness and composition of the open water samples taken on each sampling date, as well as highlighting the most abundant species within each month. Species diversity indices are then used to establish patterns and examine population changes which have occurred in each lake. Finally biovolume estimations are calculated and monthly and seasonal trends within and between lakes are described.

6.1 Composition and Abundance of the phytoplankton community

A total of 100 different species were identified within the three lakes, 72 of these 100 species were found in Lough Inchiquin, 54 in Lough Cullaun and 64 in Lough Atedaun. Of the 100 species identified, 37 belonged to the phylum Chlorophyta, 25 to phylum Bacillariophyta, 23 to phylum Cyanophyta, 6 to phylum Chrysophyta, 4 to phylum Euglenophyta, 3 to phylum Cryptophyta and 2 to phylum Pyrrophyta. Tables detailing all of the species identified in each lake under each phylum are shown in Appendix 6.1. Appendix 6.2 contains a complete list of all species found and the number of cells per ml for monthly open water samples.

Apart from the 100 species that were identified, there were also a number of cells in each sample that could not be identified. This can mainly be attributed to the small cell size, the type of counting chamber used and the level of magnification (x400). Most of the unidentified phytoplankton cells were small single cell algae, round or oval in shape (<10 μm longest linear dimension) often bearing a resemblance to *Chlamydomonas* or *Rhodomonas* sometimes with visible flagella. There were also some filamentous algae that were also difficult to identify because they were narrow in width (<5 μm), which made identifying significant taxonomic features almost impossible. Some of those that were unidentified resembled *Oscillatoria* and long thin Cyanophytes. There were also some colonial algae e.g. a *Botrycocccus* like species found in late autumn and early winter of 2004. The lack of clear cell structure (cell width < 4-5 μm) prevented identification. The centric diatoms *Cyclotella* and *Stephanodiscus* also caused taxonomic problems so these species were combined during sample enumeration. The numbers of unidentified species are listed in Appendix 6.

Monthly algal cell abundance values for each lake are shown in Figure 6.1; this graph details the different levels of cell productivity that was recorded in each lake on each sampling date.

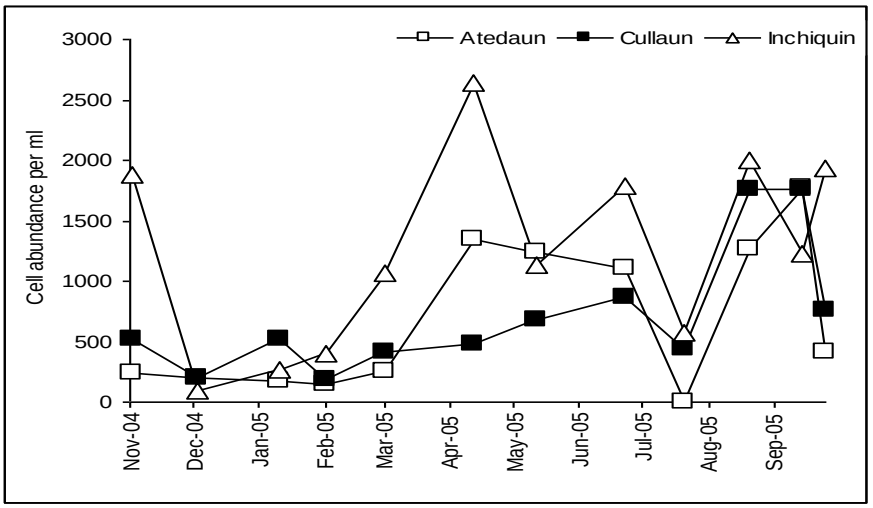


Figure 6.1 Open water monthly algal cell abundance values for Lough's Atedaun, Cullaun and Inchiquin

Lough Inchiquin had the most frequent highs in algal cell abundances followed by Lough Atedaun and then Lough Cullaun. The lowest annual abundances occurred in winter in each lake and the highest abundances occurred in April and September. Lough Atedaun and Inchiquin had distinct seasonal fluctuations. Phytoplankton dynamics in each lake are discussed in more detail in each of the following sections.

In Lough Atedaun the Chlorophyta were the most diverse group, followed by the Cyanophytes and the Bacillariophytes (Figure 6.2). Only one Pyrrophyta species was found in Lough Atedaun. In Lough Cullaun the diatoms were the most abundant phyla and Chlorophytes and Cyanophytes were the next largest groups. In general the least number of species occurred within the Chrysophyta, Cryptophyta, and Euglenophyta and Pyrrophyta groups. In Lough Inchiquin Chlorophytes were the largest group, followed closely by the diatoms and Cyanophytes. All the other four phyla were also found within Lough Inchiquin, the most diverse being the Cryptophytes and Chrysophytes followed by the Euglenophytes and the Pyrrophytes.

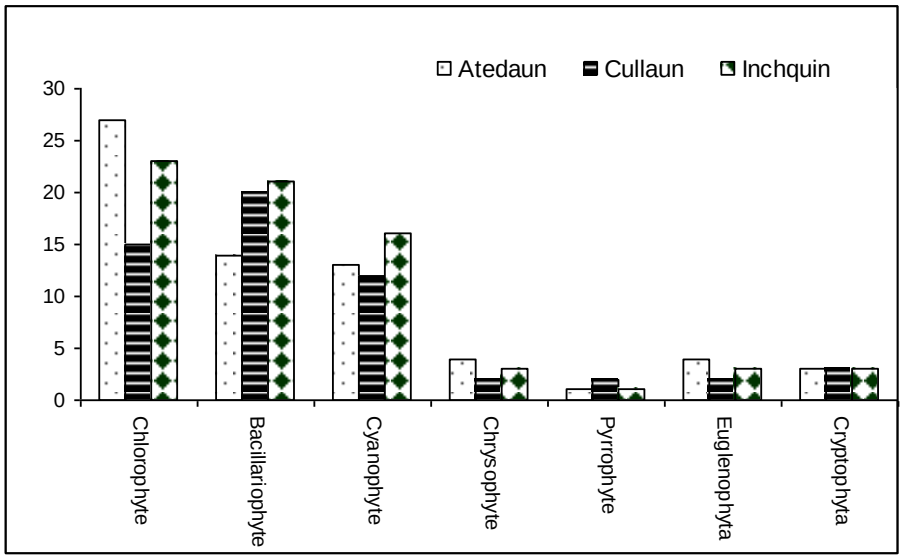


Figure 6.2 The number of species from each phyla found in Lough's Atedaun, Cullaun and Inchiquin from November 2004 to October 2005.

The most common occurring species that was found in almost every sample was the small single celled flagellate *Rhodomonas* from the Cryptophyta group. Another common algae from the same group was the larger and distinctive *Cryptomonas*. The diatom *Asterionella* formed an abundant part of the algal community in spring with in excess of 60 % relative abundance in the April samples in all three lakes. Some smaller diatoms such as *Achnanthes* and *Achnanthidium* also formed a significant part of the spring bloom that occurred in each of the lakes. The filamentous Cyanobacteria *Phormidium*, *Anabaena* and *Oscillatoria* also formed part of the overall plankton community especially in Lough Inchiquin and partly in Lough Atedaun. An unusual *Aphanizomenon* was also identified with the help of Prof. Brian Whitton in Lough Atedaun. *Dinobryon* a Chrysophyte with an unusually shaped cell dominated samples taken in early autumn. Another Chrysophtye, *Tribonema*, a filamentous algae contributed significantly to the number of cells counted in the autumn samples. The Chlorophyta *Chlamydomonas* began to appear in the summer samples along with several Chlorophytes such as *Scenedesmus, Monorophidium, Staurastrum, Xanthidium* and *Chlorella*. Algae such as *Trachlemonas, Euglena, Ceratium* and *Mallomonas* did not dominate the algal community in terms of numbers but did play a very significant role in enlarging the diversity of the phytoplankton community and in the case of the latter three increasing the algal biomass because of their large cell size.

6.2 Species richness of the phytoplankton communities

Lough Atedaun had an annual mean value of 12 species found per sample, whilst Cullaun and Inchiquin both had an annual mean value of 16 species (Figure 6.3). The lowest number of species (6) was found in Lough Atedaun in February and in Cullaun in December. The maximum number of species recorded in each lake was in the August sample. Each lake showed a seasonal pattern in terms of species richness, although species numbers at Atedaun were consistently lower than Cullaun and Inchiquin. The winter months generally had the lowest species richness values for each of the lakes. However the January sample from Cullaun had 17 different species, which was much higher than both other lakes. In March and especially April the number of species began to increase in each lake. Figures remained quite constant during summer in each lake (c. 15 species in each lake in May). There was no sample for Atedaun in July. Sixteen species were found in the July open water sample from Cullaun while the July shore sample from Inchiquin had just 9 species. In August each lake reached its annual maximum species richness value. In September figures in Cullaun remained relatively high with 22 different species identified. In Inchiquin the value was 14 and in Atedaun it was 9. In October values dropped in Inchiquin by 5 species to 9 and the opposite occurred in Atedaun, with values increasing from 9 to 14. In Cullaun figures remained quite constant and showed less change than in both other lakes.

Examination of species richness is necessary to help understand what is occurring within a population of species, in this case it is also useful in comparing and contrasting the patterns, which have occurred in each of the lakes. Species richness values do not account for the relative abundance of each species within a sample or to what extent that sample is being dominated by a single species or if it is being co-dominated by two or more species. A limit of the species richness value is that it gives all species equal weighting within the population. In modern ecology species richness is used as a valuable part of more complete indices such as the Shannon Weiner index or the Simpson index.

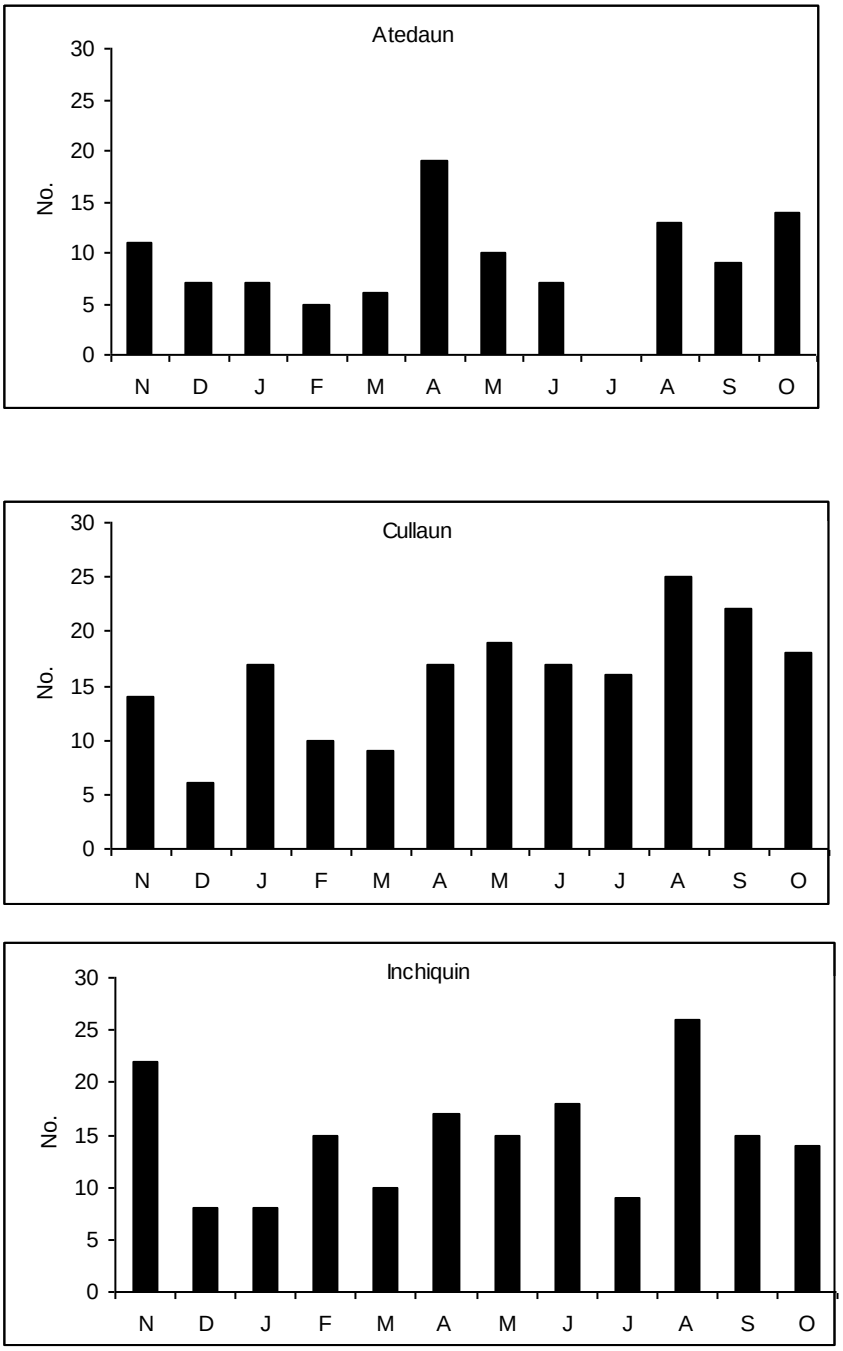


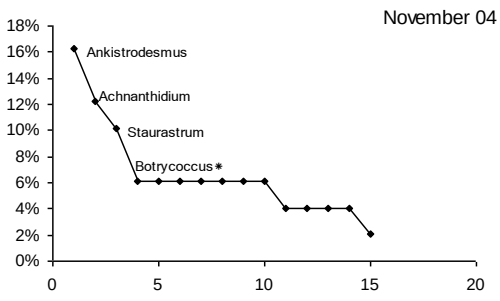
Figure 6.3 Monthly changes in species richness in samples from Lough's Atedaun Cullaun and Inchiquin (no data for July in Atedaun)

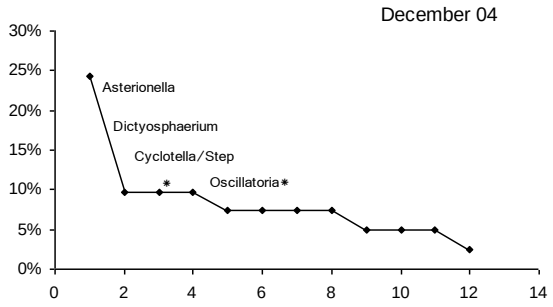
6.3 Relative abundance of species

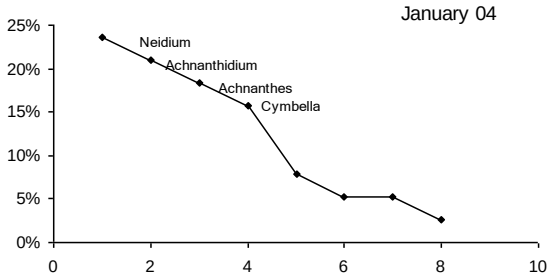
The most abundant species were identified in terms of their relative abundance in comparison to the remaining species within the sample, as it is often the most abundant species that are of most concern. Table 6.5 details the number of species that had a relative abundance of ≥ 5 % and it also shows the combined % composition of species with a relative abundance of ≥ 5 %. For example in Atedaun in November 10 species had a relative abundance of ≥ 5 % compared to three species with a relative abundance of ≥ 5 % in Cullaun in the same month. Table 6.5 also shows that the lowest number of species in all samples found with a relative abundance of ≥ 5 % is two and the maximum is 10. The Table shows which samples were co-dominated by several species and those samples that were dominated by just a few species. If a sample has only two species with a relative abundance of ≥ 5 % as in Inchiquin in April and the total composition is high (87 %) then it is obvious that such a balance will result in a small number of species dominating. The opposite occurred in November in Atedaun when 10 different species had a relative abundance of ≥ 5 % and 80 % combined composition. The four most abundant species found within each of the Atedaun monthly samples are shown in Figure 6.4, in Cullaun in Figure 6.5 and in Inchiquin in Figure 6.6. In these figures the x-axis details the rank order of species and the y-axis details percentage relative abundance of.

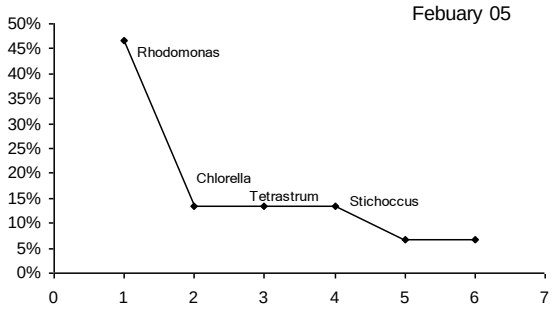
Table 6.1 Summary of the number of species with a relative abundance of ≥ 5 % and the combined percentage composition of those species

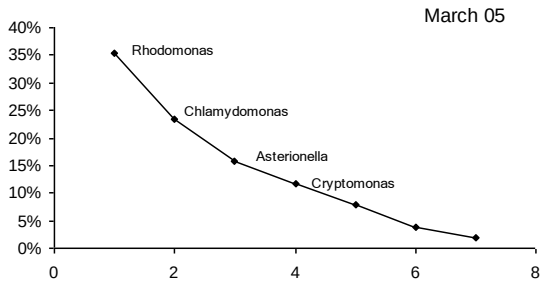
	Atedaun		**Cullaun**		**Inchiquin**	
	No. of Species ≥ 5 %	**% Composition**	**No. of Species ≥ 5 %**	**% Composition**	**No. of Species ≥ 5%**	**% Composition**
Nov-04	10	80 %	3	78 %	6	82 %
Dec-04	8	97 %	6	100 %	7	96 %
Jan-05	7	97 %	5	67 %	6	97 %
Feb-05	6	100 %	7	93 %	5	85 %
Mar-05	5	95 %	4	90 %	4	83 %
Apr-05	5	67 %	7	70 %	2	87 %
May-05	6	87 %	6	86 %	4	64 %
Jun-05	6	84 %	7	82 %	7	88 %
Jul-05	-	-	6	76 %	6	91 %
Aug-05	6	74 %	4	63 %	4	67 %
Sep-05	3	92 %	5	73 %	5	78 %
Oct-05	6	83 %	8	80 %	4	86 %

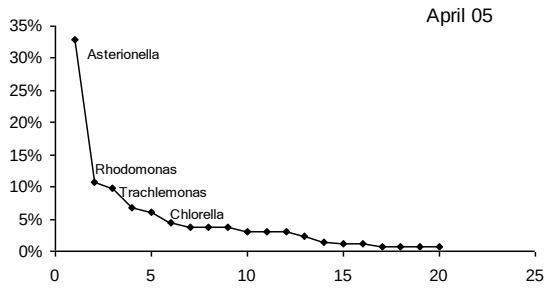

November 04
Ankistrodesmus
Achnanthidium
Staurastrum
Botrycoccus*

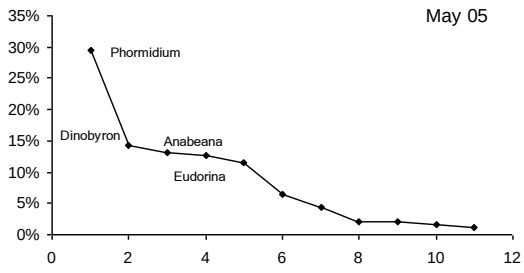

December 04
Asterionella
Dictyosphaerium
Cyclotella/Step
*
Oscillatoria*

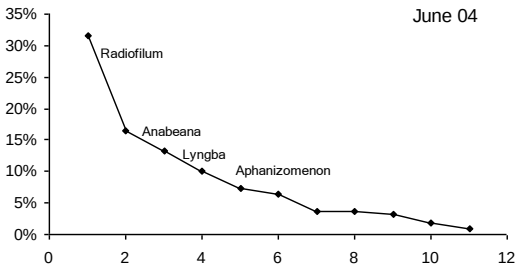

January 04
Neidium
Achnanthidium
Achnanthes
Cymbella


Febuary 05
Rhodomonas
Chlorella
Tetrastrum
Stichoccus


March 05
Rhodomonas
Chlamydomonas
Asterionella
Cryptomonas


April 05
Asterionella
Rhodomonas
Trachlemonas
Chlorella


May 05
Phormidium
Dinobyron
Anabeana
Eudorina


June 04
Radiofilum
Anabeana
Lyngba
Aphanizomenon

Rank Order

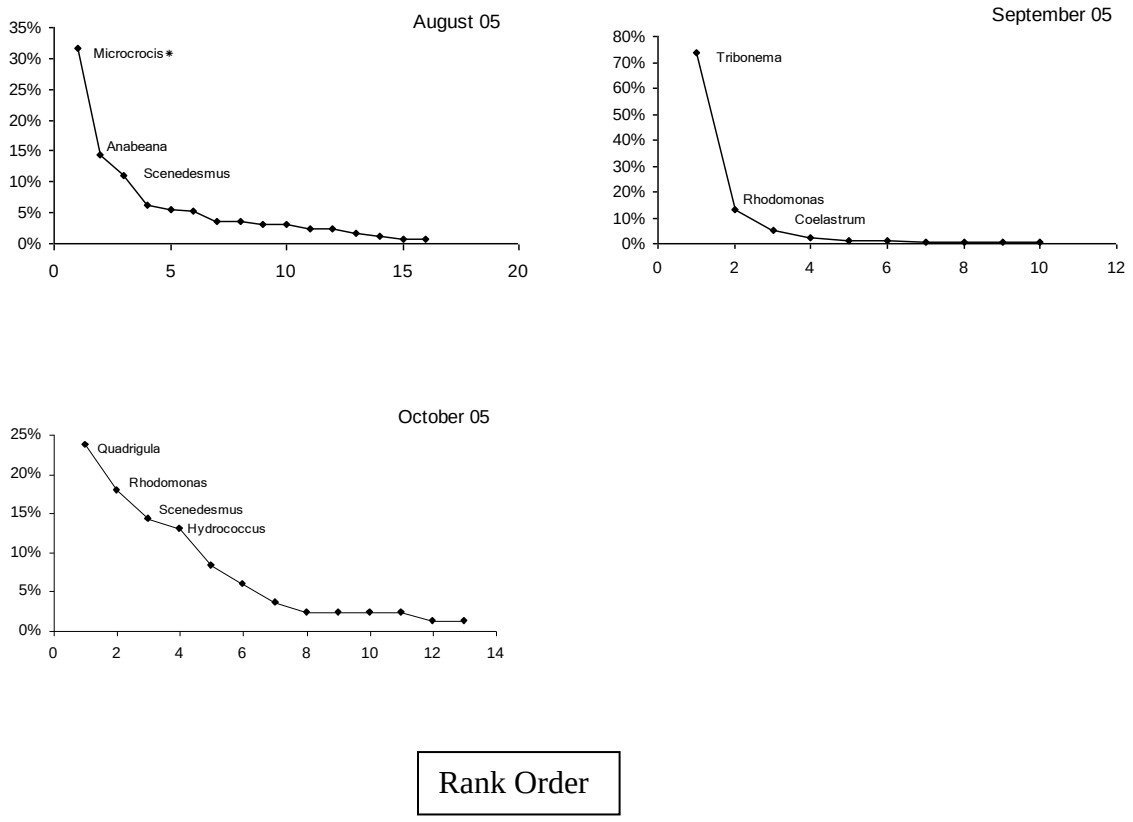


Figure 6.4 Monthly algal species abundance curves from the open water sites in Lough Atedaun. X-axis rank order, Y-axis shows % relative abundance. No data for July

Rhodomonas had the largest relative abundance in February and March in Atedaun (Figure 6.4). The diatoms *Asterionella* had the highest relative abundance in December and April while *Neidium* had the highest relative abundance in January. The Chlorophyta *Ankistrodesmus* had the highest relative abundance in November. Cyanophytes dominated in summer with *Phormidium* in May, *Radiofilum* in June and *Micrococcus* in August. *Tribonema* a filamentous Chrysophyta species had the highest relative abundance in September. During November and January several species co-dominated but in the remaining months a single species tended to have the highest relative abundance usually with an average of between 40 to 50%.

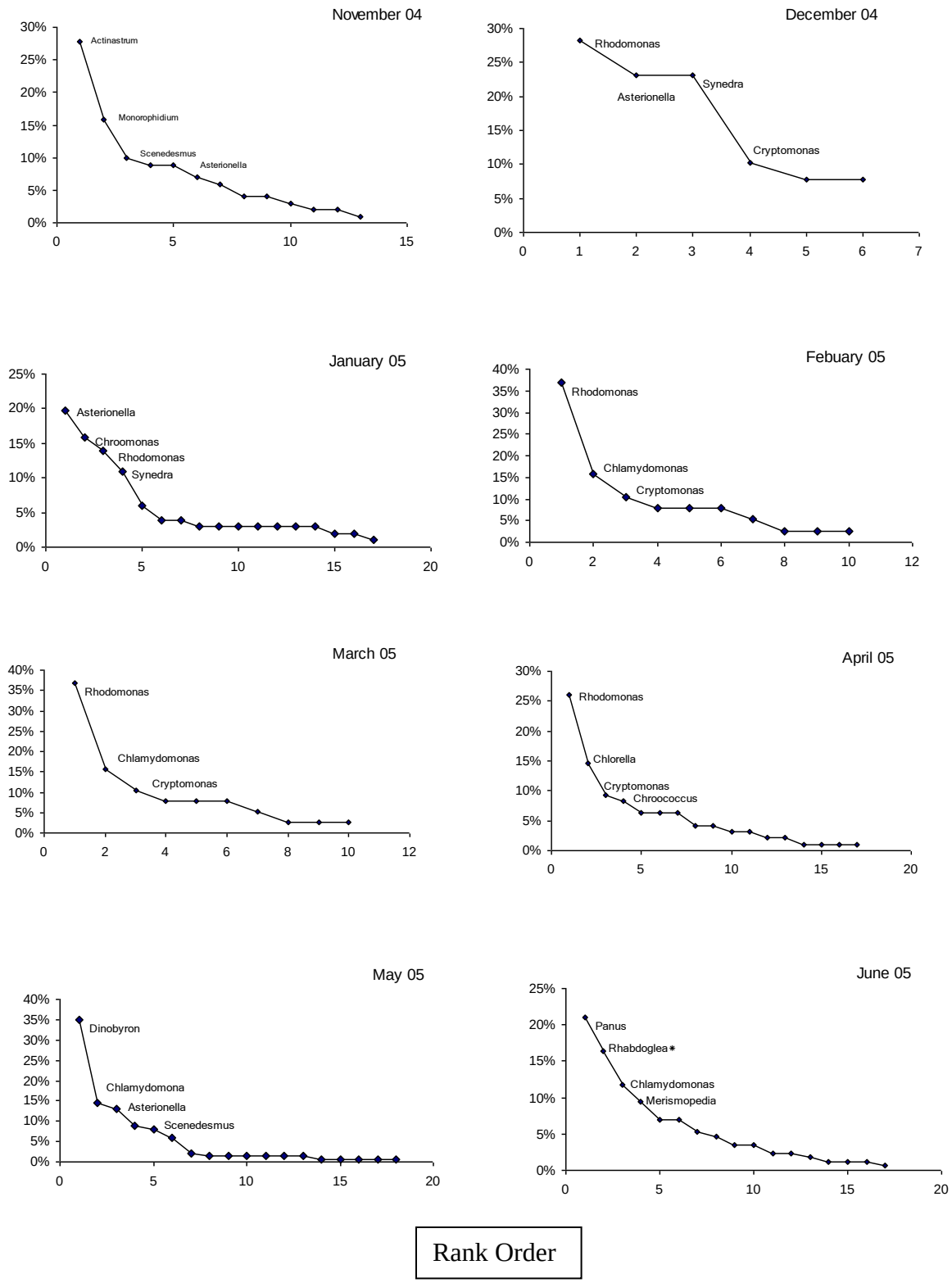


Figure 6.5 Monthly algal species abundance curves from the open water sites in Lough Cullaun, X-axis is rank order, and Y-axis is % relative abundance

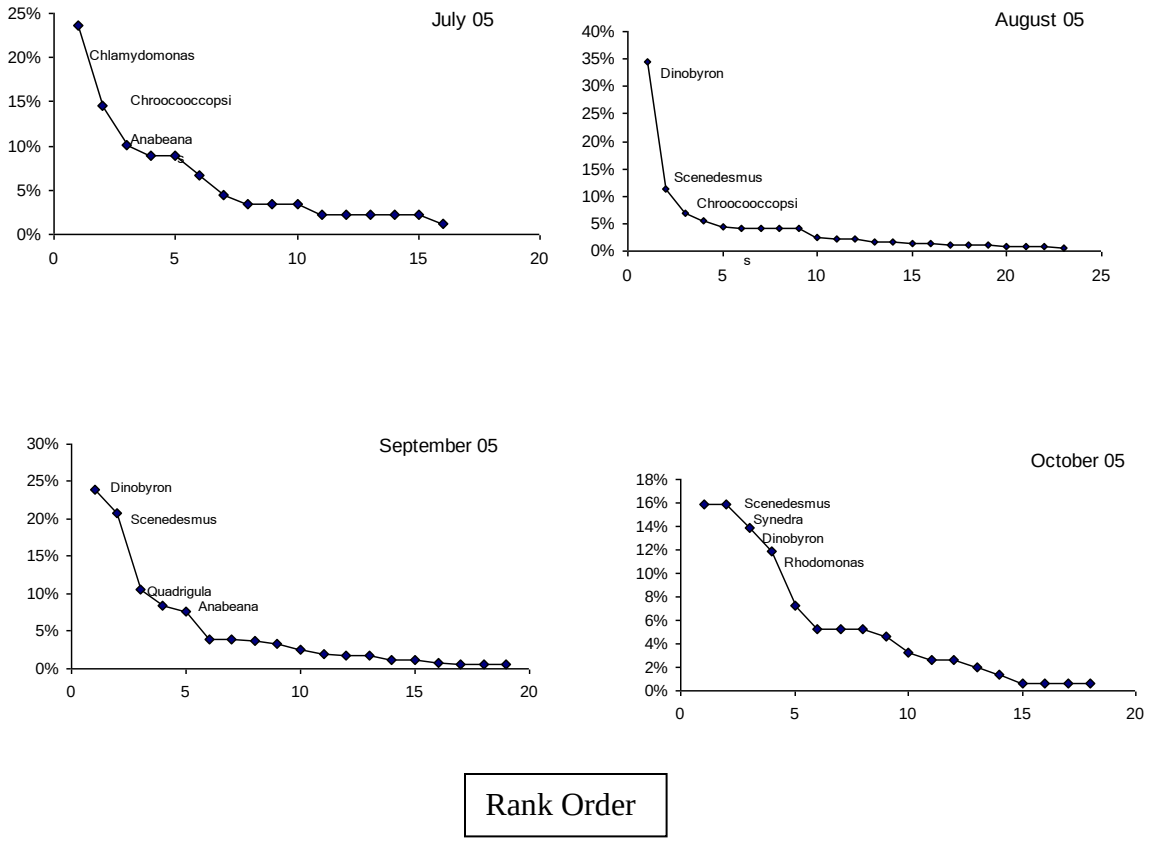
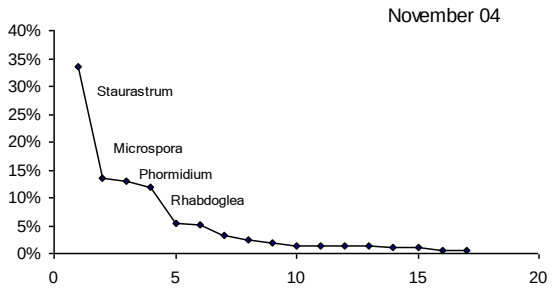
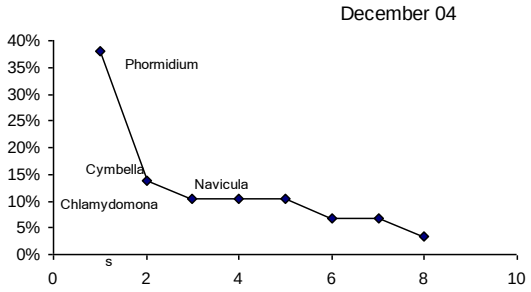
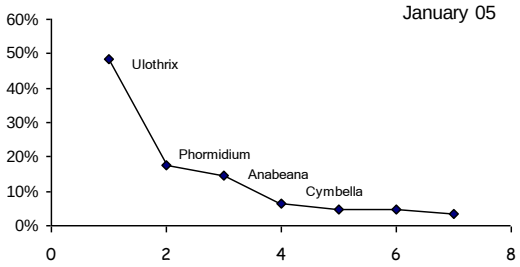


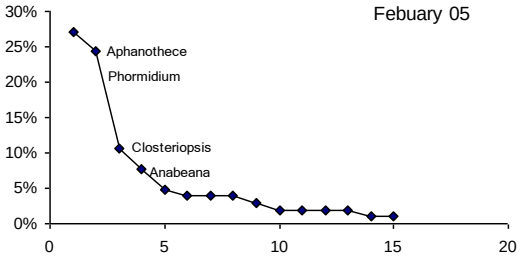
Figure 6.5 Monthly algal species abundance curves from the open water sites in Lough Cullaun, X-axis is rank order, and Y-axis is % relative abundance

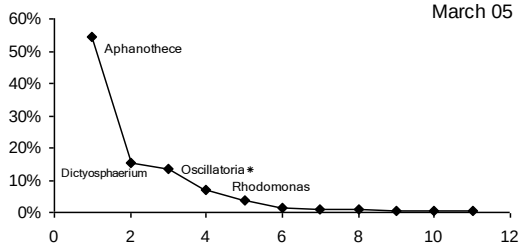
In Lough Cullaun the relative abundance of the most abundant species averaged at about 30 to 45% (Figure 6.5). The Cryptophyte *Rhodomonas* dominated on 4 occasions in December, February, March and April. *Dinobryon* from the Chrysophyta phylum dominated in May, August and September. The Cyanophyta species *Panus* dominated in June while the Chlorophyte species *Chlamydomonas* dominated in July.

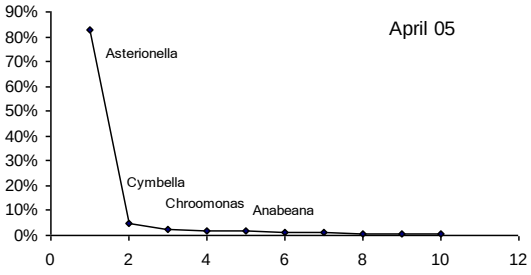

November 04
Staurastrum
Microspora
Phormidium
Rhabdoglea

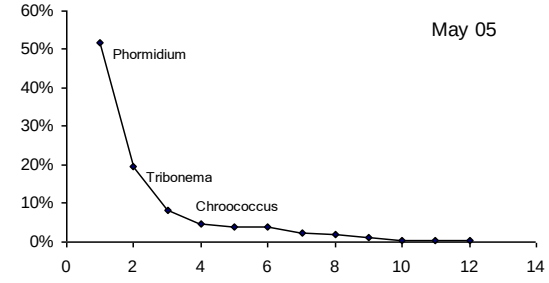

December 04
Phormidium
Cymbella
Navicula
Chlamydomonas

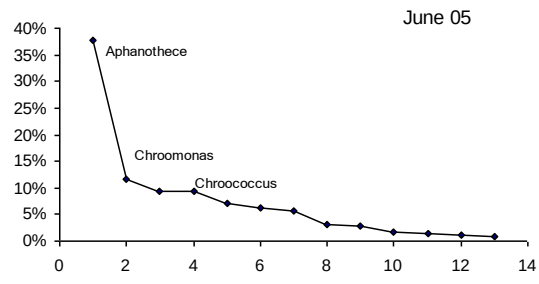

January 05
Ulothrix
Phormidium
Anabeana
Cymbella


Febuary 05
Aphanothece
Phormidium
Closteriopsis
Anabeana


March 05
Aphanothece
Dictyosphaerium
Oscillatoria*
Rhodomonas


April 05
Asterionella
Cymbella
Chroomonas
Anabeana


May 05
Phormidium
Tribonema
Chroococcus


June 05
Aphanothece
Chroomonas
Chroococcus

Rank Order

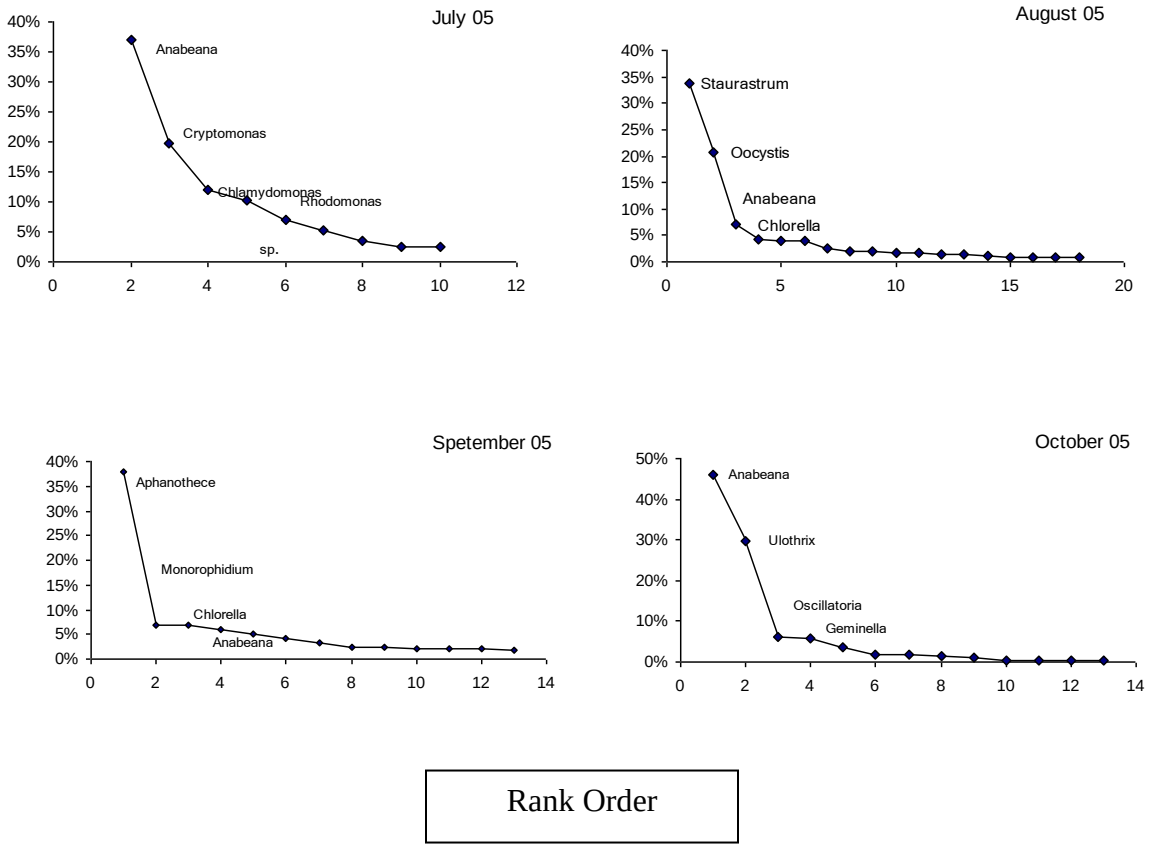


Figure 6.6 Monthly algal species abundance curves from the open water sites in Lough Inchiquin, X-axis is rank order, and Y-axis is % relative abundance

The graphs from Lough Inchiquin (Figure 6.6) show that a single algae species dominated the monthly samples on most occasions e.g. *Asterionella* (82%) in April and *Aphanothece* (55%) in March. *Staurastrum* dominated in November 2004 and in August 2005. Cyanophyte species dominated on several occasions such as in December 2005 with *Phormidium*, January with *Ulothrix*, February, March, June and September were dominated by *Aphanothece*. Some species tended to dominate more in some months than in others, for example *Aphanothece* co-dominated in February and dominated the samples in March, June and September with relative abundances of > 40 %. Many samples contained species with very low relative abundance values as seen on most graphs. To further examine the algal assemblages the Shannon Weiner (H) index and evenness (E) values have been calculated.

6.4 Diversity and structure of the open water algal community

In order to measure the diversity of species within the three lakes, the Shannon Weiner diversity index and evenness values have been calculated in order to measure and compare diversity. The Shannon index (H) reflects the number of species and their relative balance. A low H value reflecting a low number of species within a sample (Washington, 1982). Evenness (E) measures the balance between all species in a sample. An E value close to zero indicates that the community is dominated by one species and a value close to 1 indicates that the community is evenly balanced in terms of different species abundances (Washington, 1982). Shannon index and Evenness values for the study lakes are graphed in Figures 6.7 to 6.9.

In Lough Atedaun the minimum Shannon Index value (0.439) occurred in September 2005. This was due to the dominance of the species *Tribonema* which had a relative abundance of 75 %, almost completely dominating the sample. The maximum H value (1.123) occurred in November 2004 where 15 species had a relative abundance of $\geq$ 2 %. The difference between these 2 months is supported by the evenness values. September 2005 also had the lowest evenness value of 0.407 and November 2004 had the highest evenness value of 0.954, which is very close to one, which indicates an even distribution of species. The mean Shannon index value for Lough Atedaun was 0.873, with a standard deviation of ± 0.201.

Shannon Index values in Atedaun (Figure 6.7) dropped considerably during the winter months to a low in February though in spring and early summer values began to rise again. This could be due to the low species richness in winter when the Cryptophytes tend to be the main species within each lake. As spring arrives, species richness values increase, as do species abundance, which then result in an increase in the Shannon Index value. It is worth noting that evenness values did not increase when species richness and Shannon index values increased. In fact evenness values continued to drop from the first sample in November 2004 right through to June 2005. In Lough Atedaun there tended to

be a more even distribution of species during late autumn and winter than there was in late spring and early summer. Values for both indices followed a similar trend during late summer and early autumn, values dropped dramatically from August to September and then increased sharply in October. This has been explained by the dominance of *Tribonema* in the September sample. Two species accounted for 53 % of the total plankton species composition in August compared to 87 % in September while four species accounted for 69 % of the total composition in October. Details of all of these species abundances in rank order can be seen in Figure 6.3.

In Lough Cullaun the minimum Shannon index values (0.721) occurred in September 2004 and the maximum value of 1.08 occurred in August 2004 (Figure 6.8). The mean value was 0.952 with a standard deviation of ± 0.143. The Shannon index values in Lough Cullaun follow a very different monthly pattern compared to Lough Atedaun. In November 2004, Cullaun had a Shannon index value of 0.758 and an evenness value of 0.688. Shannon index values dropped to an annual low in December. Interestingly evenness had the opposite trend and increased, due to the presence of six species with a relative abundance of ≥ 5 %. Shannon index values dropped again in February and March due to the dominance of *Rhodomonas,* concomitant with a reduction in evenness values. Cell numbers (see Appendix 6) and species richness values increased in April with the increase in diatom species in Lough Cullaun. While diatoms cell numbers and species richness increased the Cryptophytes were still dominant. *Dinobryon* had high relatively abundance during late summer and autumn. From April onwards both the Shannon index and evenness values followed a similar pattern with both increasing in late summer, going through a slight decrease in early autumn and increasing again in late autumn.

In Lough Inchiquin the maximum Shannon index value occurred in August with a value of 1.017, this month also had the highest species richness value (26) though the highest evenness value did not occur in this month instead it occurred in February with a value of 0.814. The mean Shannon index value was 0.791 with a standard deviation ± of 0.180. The annual minimum Shannon index value of 0.400 occurred in April. This was also a month with a high cell count value (Figure 6.1), though it also had a very low evenness value. This is due to the dominance of the diatom species *Asterionella* which had a

relative abundance of 82 %. Figure 6.9 shows that both the Shannon index values and the evenness values followed a similar trend in Lough Inchiquin. In November 2005 there were 6 species with a relative abundance of > 5 %; the largest species *Staurastrum* had the greatest relative abundance at 34 %. The evenness value for this month was 0.716 and a total of 22 different species were identified within the sample. The low evenness value was due to the high number of species with different relative abundance values. From December onwards both diversity indices tended to follow a similar pattern, i.e. as the number of species within a sample increased or decreased so too do the distribution of species within the sample. For example April's sample resulted in the lowest annual value for both indices as *Asterionella* almost completely dominated the sample with a relative abundance of 82 %. The opposite occurred in August, with the annual maximum occurring for both indices with only two species *Staurastrum* and *Oocystis* having a relative abundance of > 10 %. What really influenced the sample was that there were nine species with a relative abundance of > 2 % and seven species with a relative abundance > 1 %. Values for both indices began to decrease from autumn 2004 and into the winter of 2004/05.

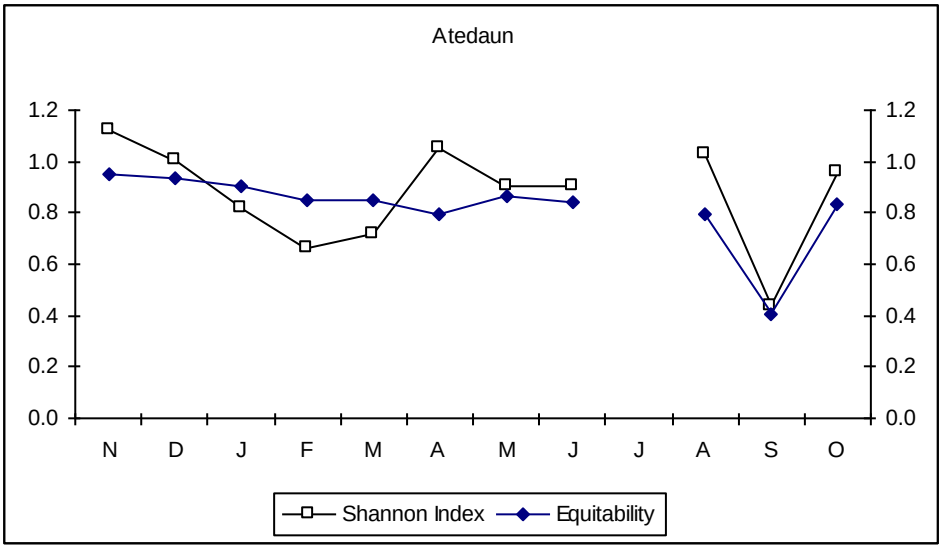


Figure 6.7 Shannon index and evenness values for Lough Atedaun (No data for July)

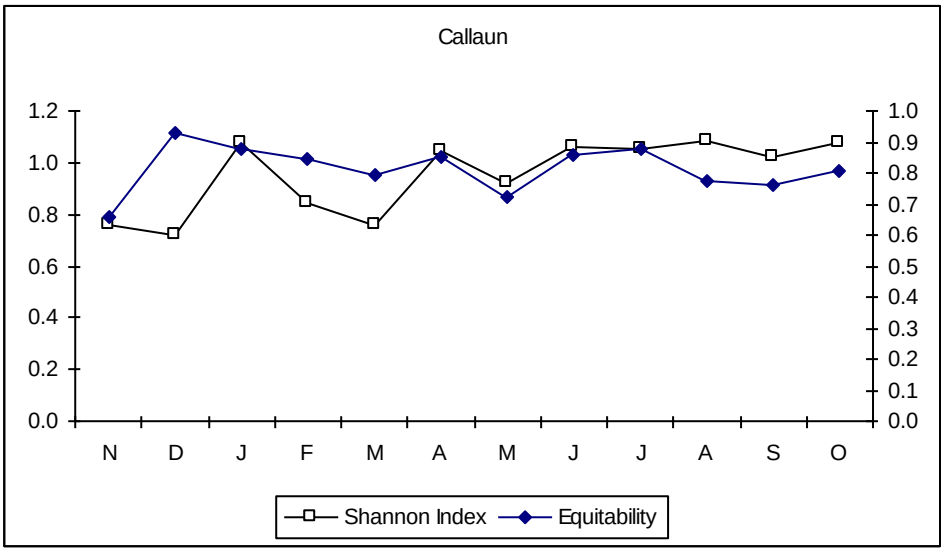


Figure 6.8 Shannon index and evenness values for Lough Cullaun from November 2004 to October 2005

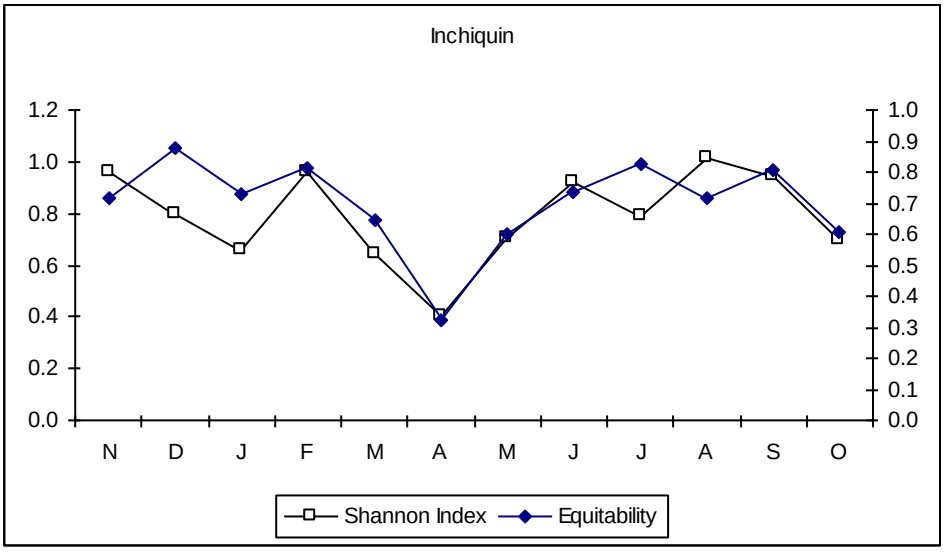


Figure 6.9 Shannon index and evenness values for Lough Inchiquin from November 2004 to October 2005

The Shannon diversity index and evenness values generally show a similar trend over the annual cycle and each lake followed a similar pattern regarding phyla dominance during each season. More specifically the monthly samples produced data that showed different species dominating samples to differing degrees in each lake. Greater monthly changes occurred in Lough Atedaun compared to the other lakes. Data from Lough Cullaun

differed from season to season but with only slight monthly changes. Significant seasonal change occurred in Lough Inchiquin.

6.5 Comparison of different spatial locations within each lake

Three algal samples (open water, inflow and outflow) were taken from each lake on a monthly basis, only the open water samples were counted except on two occassions. These were April and August the samples with with the highest species richness values. During these two months samples from three locations within each lake were identified, counted and compared using Cell abundance, Shannon Weiner index and Evenness values. This was to determine the differences and similarities between the open water, inflow and outflow samples.

In Lough Atedaun and Lough Inchiquin a greater number of cells were found in the open water sample than in the inflow and outflow sample (Figure 6.10). But in Lough Cullaun there was very little difference between each of the sites. This may be explained by Cullaun's relatively sheltered and deep inflow and outflow environments. These areas were surrounded by large reeds, with very little water movement that would cause little disruption to the phytoplankton community. In each lake cell abundance values were similar in the inflow and outflow but were lower at these sites compared to the open water sites.

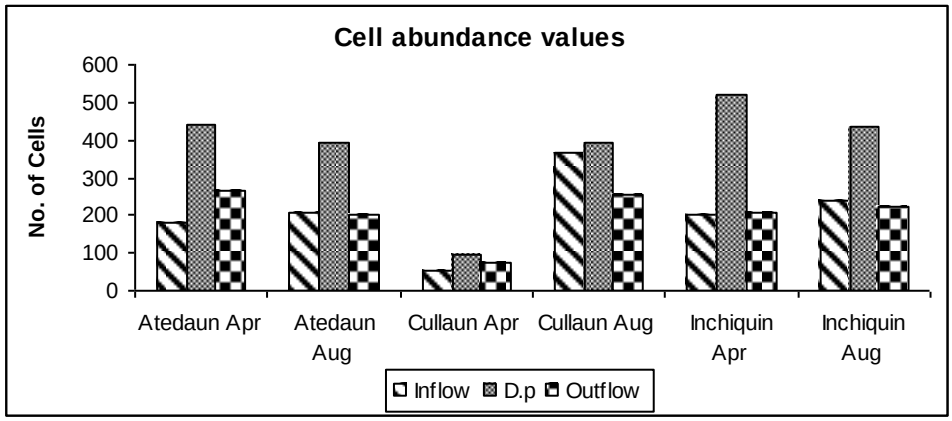


Figure 6.10 Cell abundance values for samples taken near to the inflow, outflow and deepest points in Lough Atedaun, Cullaun and Inchiquin taken in April 2005 and August 2005 (D.p = deepest point)

A higher number of species were found at the open water site at each lake which would indicate that a higher number of spcies will develop at locations that are more open and stable (Figure 6.11). Observations can made from comparing the cell abundance and species richness values. In Lough Cullaun for example the extra species at the deepest point show that conditions there were not favourable enough for them to develop significantly in terms of cell numbers. In Lough Inchiquin in April only a slight difference occurred between the number of species found near to the inflow and those found in the open water. This meant that both sites had the same number of species in April but these species developed differently at the different locations. Therefore in order for species to develop in terms of populations and cell abundance values certain conditions are required, conditions similar to those found at the deepest point. In August in Inchiquin the differences between species values was smaller between sites than the difference in cell abundance values. This again different locatiosn in lough Inchiquin may not affect the different number if species that can exist there but location certainly has an effect on the possible growth of each species in terms of abundance. Therefore location sometimes limit species richness values but certainly limits cell abundance values.

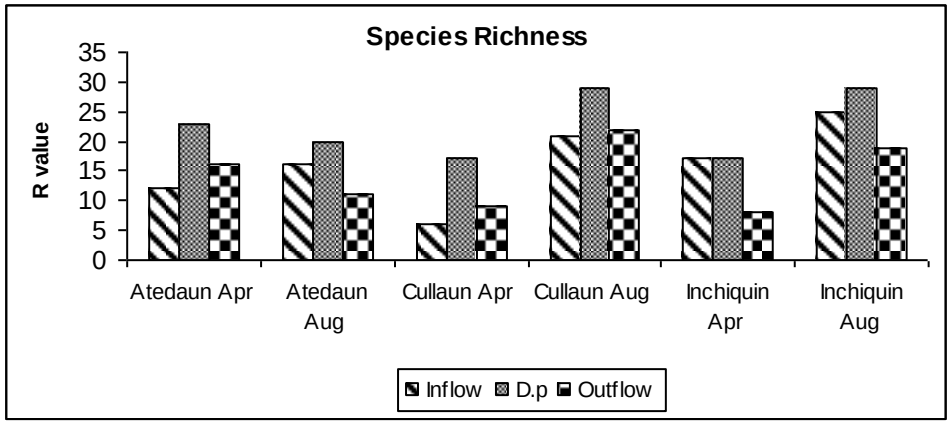


Figure 6.11 Species richness values for samples taken near to the inflow, outflow and deepest points in Lough Atedaun, Cullaun and Inchiquin taken in April 2005 and August 2005 (D.p = deepest point)

Higher Shannon index values were found in the open water sample in Lough Atedaun and Cullaun in April and August (Figure 6.12). Outflow samples were high in April and the inflow samples were high in August. In April this was due to the dominance of

Asterionella in the inflow (relative abundance = 79%), while in the open water sample it was less abundant (*Asterionella* 57%, *Cyclotella/ Stephanodiscus* 17%) and at the outflow there were 3 species with a relative abundance >10 % (*Asterionella* 33%, *Trachlemonas* 10% and *Rhodomonas* 11%). In August *Scenedesmus* co-dominated with *Monorophidium* in the inflow and open water samples while *Microcrocis* dominated with *Scenedesmus* and *Monorophidium* having (≥ 10%) at the outflow. In Lough Cullaun higher diversity values were found in open water samples and outflow compared to the inflow samples. *Asterionella* dominated the inflow sample in Lough Cullaun along with *Synedra* and *Rhodomonas*. Notably *Asterionella* failed to show up in samples taken from the open water and the outflow samples in Lough Cullaun. Instead *Rhodomonas* and *Chlamydomonas* co-dominated with 5 other species having a relative abundance of >5 % and 10 species having a relative abundance of <5 %. In August in Lough Cullaun, *Dinobryon* dominated at each site though more so at the inflow (64%) and outflow (57%) than in open water (31%), which may suggest that preference for littoral areas. At the deepest point there were 4 species with a relative abundance of ≥ 5 % (seven with a relative abundance > 4%) and this contributed to the high diversity value at this site. At the outflow *Dinobyron* dominated as it did in the inflow. In April in Lough Inchiquin very low diversity values were found in the open water samples and at the outflow due to the dominance of *Asterionella* (relative abundance > 80%) in both these samples.

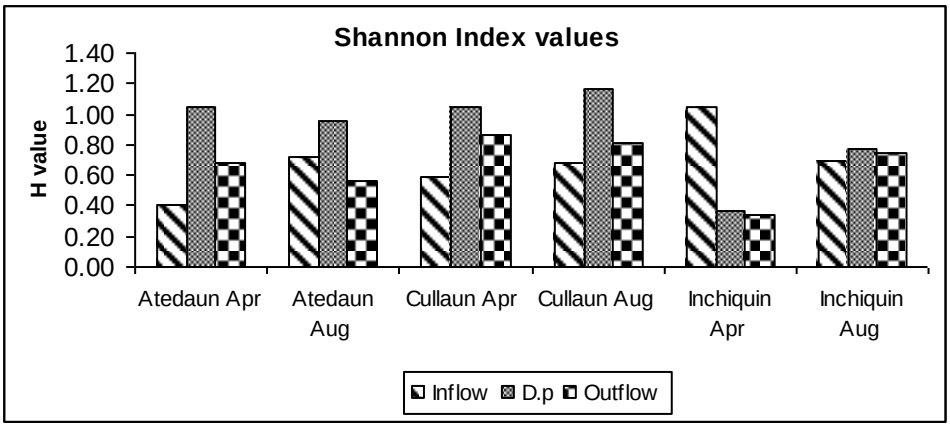


Figure 6.12 Shannon index values for samples taken near to the inflow, outflow and deepest points in Lough Atedaun, Cullaun and Inchiquin taken in April 2005 and August 2005 (D.p = deepest point)

High evenness values were spread among the open water, inflow and outflow samples between months with no obvious trends (Figure 6.13). This can be attributed to the fact that although a site may dominate in terms of cell abundance, species richness and diversity values this dominance does not transfer over to the proportional distribution of species in a sample. In Lough Atedaun the most even distribution of species occurred at the outflow, with a similar distribution occurring in April and August though significantly with different species. High evenness values occurred in Lough Cullaun in April, especially at the outflow, which was dominated by *Asterionella* as mentioned previously. In August in Lough Cullaun the open water had the highest evenness value followed by the outflow and then the inflow. A very low evenness value was found in Lough Inchiquin in the open water and the outflow in April due to the dominance of *Asterionella*. In August very similar evenness values occurred at each site due to the similar abundance of similar species in each of the samples.

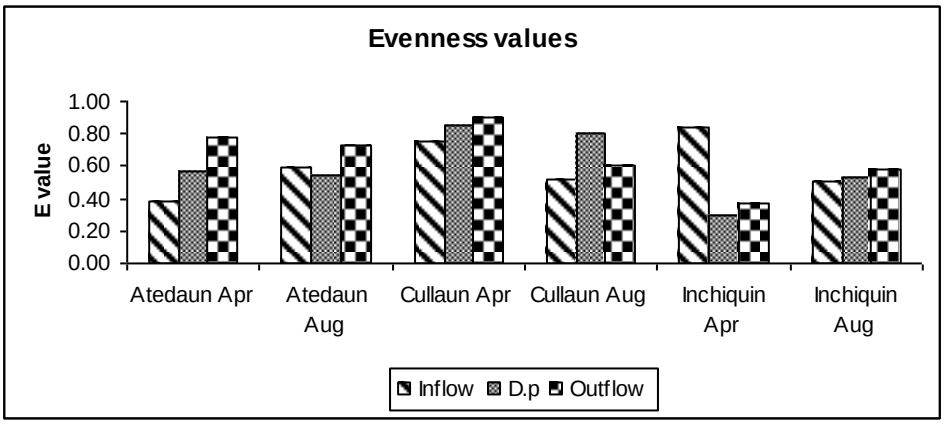


Figure 6.13 Evenness values for samples taken near to the inflow, outflow and deepest points in Lough Atedaun, Cullaun and Inchiquin taken in April 2005 and August 2005 (D.p = deepest point)

Comparison of phytoplankton samples taken at different sites in each lake indicated that algal assemblages did differ between different sites. It also became evident that an algal species could show a preference for a certain site and thus could be more adapted to certain conditions. This was also evident when cell values were compared between sites, certain species had higher populations at different sites, which could infer that some species are better at adapting to certain conditions. Certainly it was evident that algal

assemblages from open water sites tended to have larger populations and higher diversity values than assemblages near to the inflow or outflow.

6.6 Algal Biovolume

Phytoplankton cell size varies greatly among different genera and even between different individuals. Size can range from a few micrometers to a few millimetres. Biovolume is an important measurement in the study of phytoplankton ecology, although the calculation of phytoplankton biovolume is a difficult and tedious task (Hillebrand *et al*., 1999). The difficulty in calculating the volume (μm^3) and surface area (μm^2) of phytoplankton cells is due to the complexity and diversity of algal shapes. Correct calculation also requires the correct equipment and a taxonomist with a substantial amount of experience. The calculation of biovolume proved to be one of the most challenging aspects of this study.

The Clare lakes phytoplankton dataset was reduced to include species that make up the bulk of the phytoplankton biomass. Species with a relative abundance of ≥ 5% abundance on at least one occasion were included in the data set. This reduced the data set to 61 species, which are listed in Table 6.9, along with their surface area and biovolume. The cell volume (μm^3) for each species was multiplied by the number of cells per ml for that species. This figure then was used to determine the total biovolume contribution of each species, each algal group and also the monthly biovolume for each lakewater sample.

Table 6.2 Surface area and cell volume of the reduced data set (i.e. algae with a relative abundance of ≥ 5 % in at least one sample). Asterisk signifies colony measurements.

Class	Genus	Cell volume (μm^3)	Cell surface area (μm^3)
Chlorophyta	*Actinastrum*	771	338
Chlorophyta	*Ankistrodesmus*	240	330
Chlorophyta	*Botrycoccus**	132701	14073
Chlorophyta	*Chlamydomonas*	382	254
Chlorophyta	*Chlorella*	697	380
Chlorophyta	*Closteriopsis*	1931	1571
Chlorophyta	*Crucigenia*	0	77
Chlorophyta	*Coelastrum*	180	154
Chlorophyta	*Dictyosphaerium*	268083	20106
Chlorophyta	*Eudorina*	3591	1134

Class	Genus	Cell volume (μm^3)	Cell surface area (μm^3)
Chlorophyta	*Klebsormidium*	226	207
Chlorophyta	*Microspora*	804	503
Chlorophyta	*Monorophidium*	42	92
Chlorophyta	*Oocystis*	636	400
Chlorophyta	*Quadrigula*	242	175
Chlorophyta	*Radiofilum*	335	408
Chlorophyta	*Scenedesmus*	264	227
Chlorophyta	*Staurastrum*	5730	1694
Chlorophyta	*Tetrastrum*	31	31
Chlorophyta	*Ulothrix*	704	452
Bacillariophyta	*Achnanthes*	126	151
Bacillariophyta	*Achnanthidium*	707	528
Bacillariophyta	*Asterionella*	1140	1066
Bacillariophyta	*Cyclotella/Steph*	14137	2827
Bacillariophyta	*Cymbella*	724	519
Bacillariophyta	*Diatoma*	3054	1484
Bacillariophyta	*Encyonema*	48	99
Bacillariophyta	*Fragilaria*	5529	2865
Bacillariophyta	*Gomphonema*	461	419
Bacillariophyta	*Navicula*	1188	674
Bacillariophyta	*Neidium*	2721	1255
Bacillariophyta	*Suriella*	77	126
Bacillariophyta	*Synedra*	6400	3328
Bacillariophyta	*Tabeleria*	9324	6655
Cyanophyta	*Anabeana*	268	201
Cyanophyta	*Aphanizomenon*	339	641
Cyanophyta	*Aphanothece*	8	21
Cyanophyta	*Chroococcus*	1437	616
Cyanophyta	*Chroococcopsis*	524	314
Cyanophyta	*Gleocapsa**	9203	2124
Cyanophyta	*Lyngba*	382	297
Cyanophyta	*Microcrocis**	157	166
Cyanophyta	*Merismopedia*	16	40
Cyanophyta	*Oscillatoria**	4021	2111
Cyanophyta	*Pannus*	14	28
Cyanophyta	*Phormidium**	42	71
Cyanophyta	*Pseudanbaena*	382	254
Cyanophyta	*Pseudosphaerocystis*	335	408
Cyanophyta	*Rhabdoglea*	64	94
Cyanophyta	*Stichococcus*	71	-59
Cyanophyta	*Tolypothrix*	283	245
Chyrsophyta	*Chyrsococcus*	628	711
Chyrsophyta	*Dinobyron*	2832	1184
Chyrsophyta	*Tribonema*	1001	649
Chyrsophyta	*Mallomonas*	31198	7435

Class	Genus	Cell volume (μm^3)	Cell surface area (μm^3)
Euglenophyta	*Euglena*	24328	62557
Euglenophyta	*Lepocinclis*	1437	688
Euglenophyta	*Trachlemonas*	564	1658
Cryptophyta	*Chroomonas*	7125	22568
Cryptophyta	*Cryptomonas*	4691	1465
Cryptophyta	*Rhodomonas*	704	2123

Monthly changes in total biovolume for each lake are shown in Figure 6.14. The most notable feature from this figure is that Inchiquin had the highest biovolume, whilst Cullaun and Atedaun had lower biovolume values. Lough Atedaun also had the lowest biovolume on the highest number of occasions. Each of the lakes followed a similar seasonal pattern with values decreasing in winter, increasing through spring and early summer, then decreasing towards late summer and increasing again in early autumn. Atedaun had some of the lowest levels especially during January, February and March. Another factor worth noting is that the spring bloom that occurred in April in Inchiquin and Atedaun did not occur to the same extent in Lough Cullaun. From July onwards Cullaun and Inchiquin had similar biovolume values whilst Atedaun's values were lower, this occurrence was not unexpected.

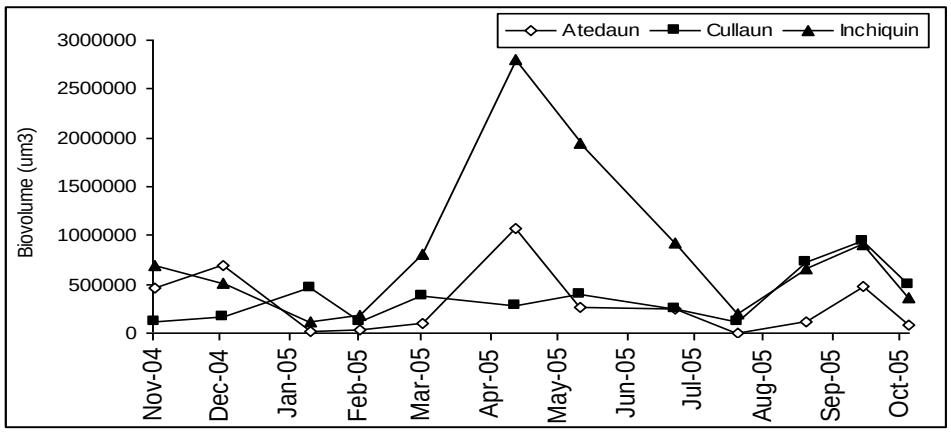


Figure 6.14 Monthly changes in total biovolume for each study site

6.6.1 Biovolume of the most abundant species

The number of species in each sample with a biovolume of >5 % and the total composition of those species with a biovolume > 5 % are shown in Table 6.10. Mean values for each lake are also shown. In Figure 6.15 the number of species with a biovolume of > 5 % are graphed; the patterns show that the three lakes do not follow similar patterns. The different pattern in each lakes shows that in terms of algal dynamics each lake displays different patterns and hence needs to be examined seperatly in order to be understood. It also shows the complexity of algal dynamics even in lakes within similar geographical areas.

Table 6.3 Number of species with a biovolume > 5% and the total composition of these species

	No. Species > 5%	**% Composition**	**No. Species > 5%**	**% Composition**	**No. Species > 5%**	**% Composition**
Nov 04	2	93	5	94	7	82
Dec 04	2	92	6	100	3	97
Jan 05	6	99	4	93	3	91
Feb 05	4	100	4	96	3	77
Mar 05	5	99	4	91	1	98
Apr 05	9	95	6	79	2	92
May 05	7	89	3	92	3	91
June 05	7	90	6	90	4	89
July 05	-	-	8	93	4	87
Aug 05	6	88	4	75	9	83
Sep 05	5	85	6	75	4	80
Oct 05	6	91	5	79	7	94
Mean	**5**	**93**	**5**	**88**	**4**	**88**

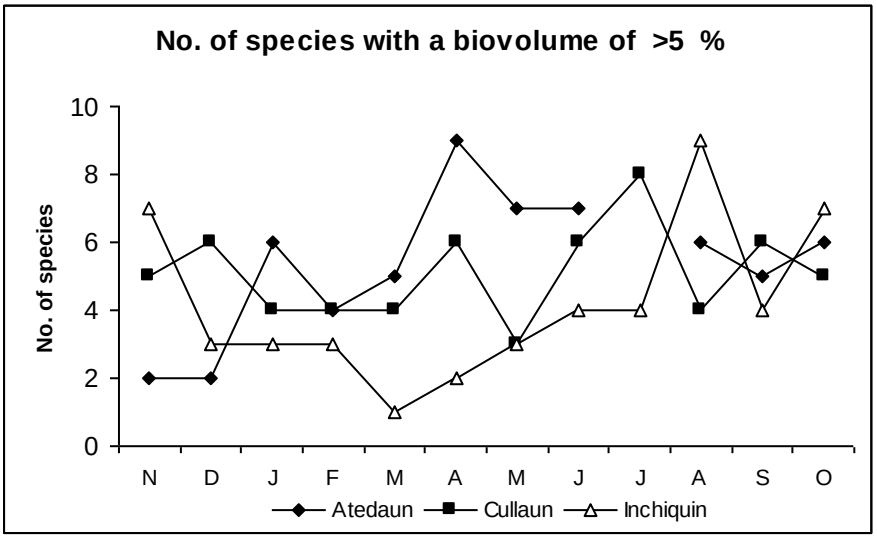


Figure 6.15 Number of species with a relative abundance of > 5% in Lough Atedaun, Cullaun and Inchiquin

6.6.2 Biovolume of phytoplankton in Lough Atedaun

In the first month of sampling in November 2004 the Chlorophyte *Botrycoccu*s accounted for 87 % of the total biovolume in Lough Atedaun (Figure 6.16). The dominance of this species did not show up when the species cell abundance values were examined, as this is a colonial algae with very small cells that are tightly compacted together. Therefore it was impossible to count the number of cells and instead the number of colonies per ml was counted. *Dictyosphaerium* another colony of cells dominated the December 2004 sample, and again this was not picked up in the cell counts due to the reasons mentioned previously. Both of these colonies were quite difficult to identify. The Cryptophytes *Rhodomonas*, *Cryptomonas* and *Chroomonas* contributed significantly to the total algal biomass, especially during the winter months. The smaller *Rhodomonas* had a high cell count throughout the year though its small size meant that it had a low percentage biovolume. *Cryptomonas*, which had a very low counts, had a high biovolume contribution due to its much larger size. *Chroomonas* occurred less frequently than the other two algae, however, its cell volume ranks it between the other two algae in terms of size but its low occurrence meant that it had a low algal biovolume. The dominance of

Cryptophytes during winter months can mean that they either are better adapted to colder temperatures or it may also signify that they are out-competed during warmer months.

In January a month with very low cell counts the diatoms dominated in terms of algal biovolume, especially smaller diatoms such as *Achnanthes, Achnanthidium,* and a small *Cymbella*. February resulted in the diatom *Tabellaria* and a mixture of Cryptophytes dominating the biovolume. In March the diatom *Asterionella* contributed 47 % of the biovolume, *Cryptomonas* had 30 % of the biovolume and the Cyanophyte *Oscillatoria* also began to appear with 13 % of the total biovolume. In April cell counts increased significantly, there were nine species with a biovolume of greater than 5 % as shown in Table 6.3. *Asterionella* had 47 % of the biovolume and *Cyclotella* and *Stephanodiscus* combined had 16 % of the biovolume. Two new species co-dominated in May these were the Chlorophyte *Eudorina*, which is a colony of large single cells (c. 19 µm width), spherical in shape and the Chrysophyte *Tribonema* which is semi-cylindrical in shape but also appears in colonies. Therefore we can now see a move from smaller single cell species in winter to larger species in summer many of which appear in colonies. June was dominated by the Euglenophyte *Euglena* a large single celled algae. Unfortunately no data exists for July. However by August there were six species with a biovolume greater than 5 %, as shown in Table 6.3. Three of these species the Pyrrophyte *Ceratium*, the Chrysophyte *Dinobyron* and the Chlorophyte *Cryptomonas* had a biovolume greater then 10 %. The Chlorophyte *Scenedesmus*, the Euglenophyte *Phacus* and the diatom *Cocconeis* each had a biovolume of less than 10 % but greater than 5 %. The filamentous Chrysophyte *Tribonema* dominated September's sample with the Cryptophytes dominating October's sample. In the summer months filamentous Cyanophytes such as *Anabaena*, and an unusually shaped *Aphanizomenon* (Prof. Brian Whitton, pers. comm.) and *Oscillatoria* all appeared but never dominated in terms of biovolume. In contrast, the Cyanophytes dominated in June and August in Lough Atedaun in terms of cell abundance but due to their sometimes small size, other much larger algae contributed more to the total biovolume within the lake.

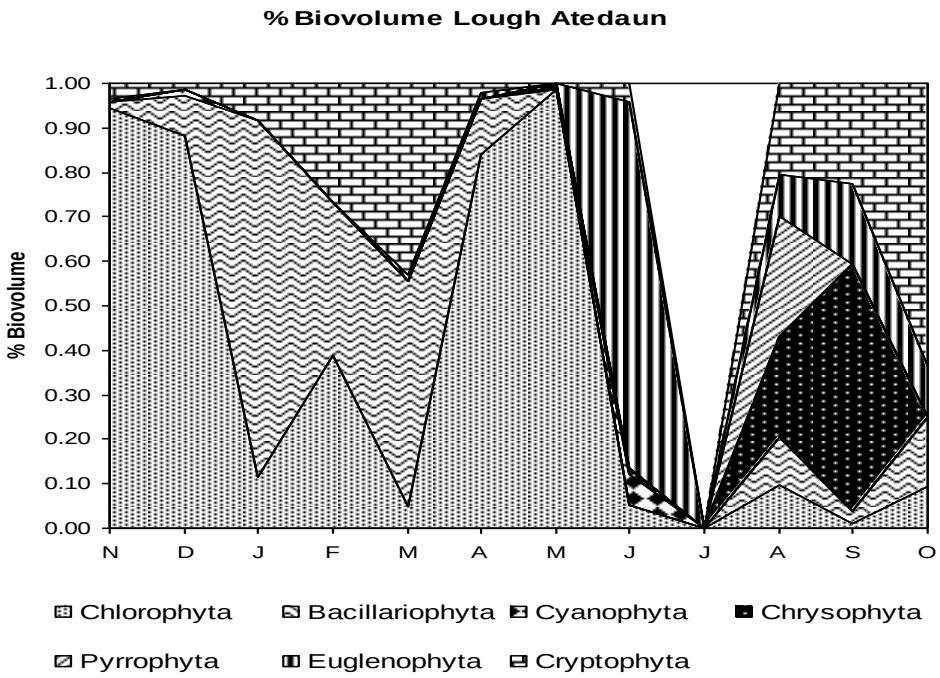


Figure 6.16 % Biovolume of seven phytoplankton phyla found in Lough Atedaun from November 2004 to October 2005 (blank white area indicates a missing sample)

6.6.3 Biovolume of phytoplankton in Lough Cullaun

In Lough Cullaun there were far less Chlorophytes dominating in term of algal biovolume than in Lough Atedaun (Figure 6.17). A predominance of all other groups especially the diatoms, Chrysophytes and Pyrrophytes was evident. Relative abundance values in Figure 6.4 show that *Rhodomonas* and *Dinobryon* were the two most abundant species in terms of relative abundance. In Lough Cullaun the mean number of species with a composition of > 5 % was 5 with the mean total composition of these species amounting to 88 %. In October *Asterionella, Actinastrum, Oscillatoria, Cryptomonas* and *Rhodomonas* all had a biovolume of greater than 5 %, with *Asterionella* being the highest at 40 %. *Asterionella* had a biovolume of greater than 10 % on six occasions and > 5 % on two more occasions in Lough Cullaun. It had the highest mean biomass of any species at 16 % compared to a mean biomass of 3 % in Lough Atedaun (and 7 % in Lough Inchiquin (see next section)).

Asterionella dominated in Lough Cullaun in March (in comparison to March and April Atedaun). *Asterionella* along with *Fragilaria* and *Synedra* dominated in November's sample. *Asterionella, Pinnularia, Synedra* as well as *Rhodomonas* and *Cryptomona*s dominated in January's sample. Very few algae were found in the February sample. In terms of relative abundance *Rhodomonas* dominated but in terms of biovolume *Euglena* dominated. March saw the return of some Cyanophytes (*Anabaena*, *Gleocapsa*, *Oscillatoria*, *Chroococcus* and *Chroococcopsis)* that had not appeared in any great abundance over the winter months. March also saw the appearance of *Stephanodiscu*s / *Cyclotella*, with a relative biovolume greater than 2% in 11 samples and a mean annual biovolume of 11 %. In April *Dinobryon* appeared with a relative biovolume value of 4 %. This species appeared in the following six monthly samples with an annual mean biovolume of 12 %. In May three species co-dominated *Asterionella*, *Stephanodiscus* / *Cyclotella* and *Tribonmea*. *Ceratium* the Pyrrophyte appeared in the samples collected in June, July and August with a high biovolume (< 35 %). In June *Fragilaria* appeared with a relative biovolume of 9 % and continued to appear in the remaining samples. In July *Chlamydomonas* a small single celled Chlorophyte with low biovolume had a sample biovolume of 7 % this was due its very high cell count value. In August *Dinobryon* dominated with a biovolume of 47 %. It also dominated in terms of relative cell abundance. In September there were 10 species with a biovolume ≥ 2 % and six species with a biovolume ≥ 5 %. *Dinobyron* and *Cyclotella / Stephanodiscus* dominated with relative biovolumes greater than 20 % but *Gymnodinium* a Pyrrophyte and *Mallomonas* a Chrysophyte both had biovolumes of 8 %. *Asterionella* and *Fragilaria* also contributed both having biovolumes of 8 %. *Synedra* a diatom along with *Cyclotella / Stephanodiscus* and *Tribonema* were most abundant in the sample collected in October.

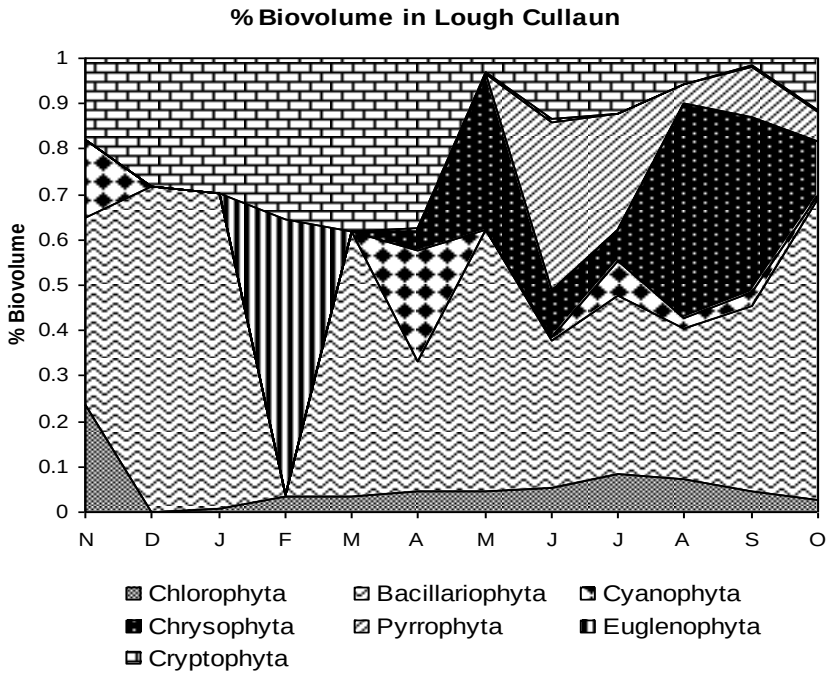
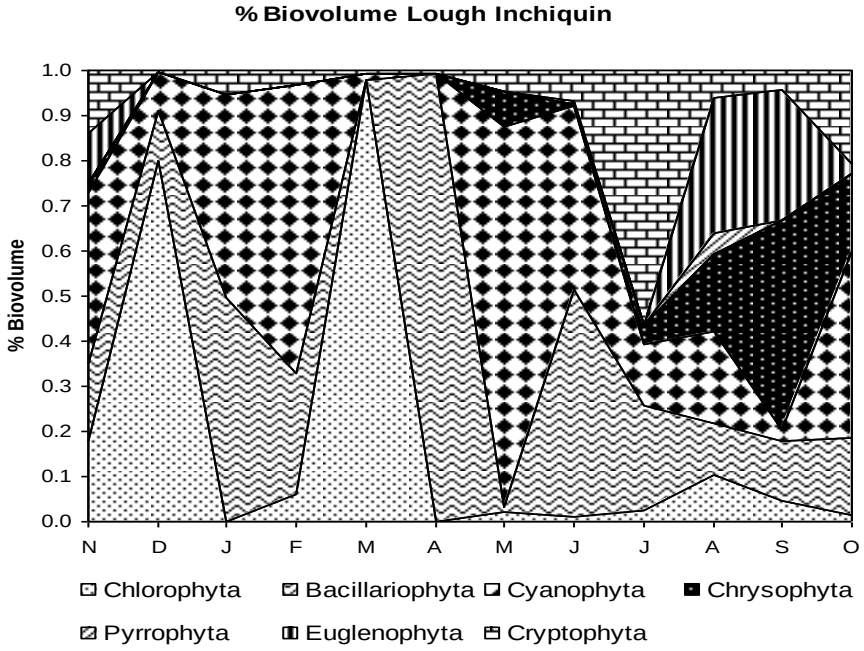


Figure 6.17 % biovolume of seven phytoplankton phyla found in Lough Cullaun from November 2004 to October 2005 (blank white area indicates a missing sample)

6.6.4 Biovolume of phytoplankton in Lough Inchiquin

From Figure 6.18 it is evident that a different biovolume pattern took place in Lough Inchiquin compared to the other two lakes. There was a noticeable presence in Cyanophyte biovolume compared to both other lakes; this resulted in a reduction in Chlorophyte, Bacillariophyte and Cryptophyte presence. The mean number of species with a biovolume > 5 % was four and the annual mean total composition of biomass was 88 %. In November there were 12 species with a relative abundance > 2 %. The filamentous Cyanophyte *Oscillatoria* had the highest biovolume at 37 % and the remaining 11 species had a biovolume < 11 %. *Oscillatoria* had the highest mean biovolume at 20 % and appeared in eight of the monthly phytoplankton samples taken from Lough Inchiquin.

Botrycoccus completely dominated December's sample similar to the sample taken from Lough Atedaun. In January *Cyclotella / Stephanodiscus* and *Oscillatoria* co-dominated. In March *Dictyosphaerium* completely dominated the sample with a biovolume of 98 %. In April *Asterionella* dominated with a biovolume of 78 %. Oscillatoria dominated in May and the diatom *Fragilaria* and the Cyanophyte *Gleocapsa* dominated in June's sample. *Cryptomonas* had the highest biovolume at 56 % in July's sample. In August there were 13 species with a relative biovolume >2 %. August resulted in the highest species richness values for each of the lakes. In September *Mallomonas* and *Euglena* dominated, these species also appeared in both other lakes. In October several species co-dominated, these were the Cryptophytes along with 2 Cyanophytes (*Anabaena* and



.

Figure 6.18 % Biovolume of seven phytoplankton phyla found in Lough Inchiquin from November 2004 to October 2005

Phormidium) as well as the Chrysophyte *Synura.*

In summary, the general seasonal pattern of contribution of each algal phylum's contribution to the total biovolume of the three study lakes combined is illustrated in Figure 6.19. Chlorophytes dominated in winter and summer, Bacillariophytes in spring

and autumn, the Cyanophytes, Cryptophytes tend to have a significant contribution in each season, whilst the Chrysophytes showed a preference for late summer and autumn.

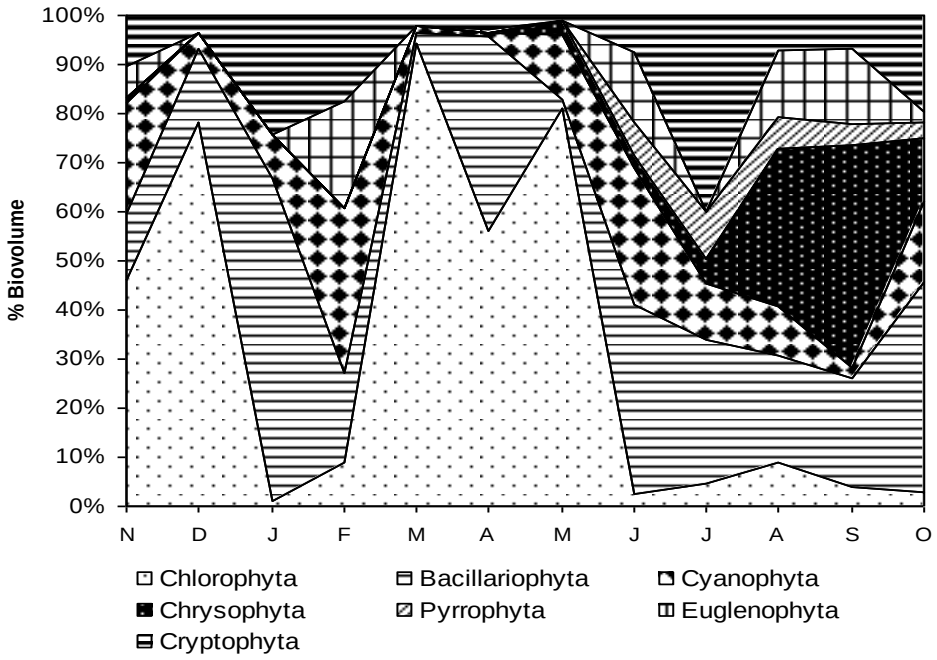


Figure 6.19 Total % biovolume of seven phytoplankton phyla in the 3 lakes combined

6.7 Summary

On a basic level this study provides a floral account of the algal communities of these three lakes over a 12 month period and provides a very detailed account of changes in taxonomic composition of each lake. More detailed analysis of this floral account followed involving more indepth ecological analyisis. This showed that some similarities did occur but in general it showed that each of these lakes were different habitats which had different alagal communities developing in different ways. Detailed analysis shows the complexity of algal communities and also serves to highlight the possible limits of one off and limited sampling approaches.

It is eveident from these lakes that algal communities change and develop on a seasonal basis, a factor well known in algal studies. What was also evident was that location had a significant affect on algal populations and that certin conditions were more supportive to the development of algal communities. The measurement of algal speices and the use of

biovoulume also showed that a simple floral description of algal communities is nesseacry but alos limited. The use of biovolume was useful and provided an ability to view the algal communities developing in terms of size and also described the seasonal growth of different phyla, a useful view of algal change qand development.The variety od approaches used in this study allowed for an indepth and detiled view of the algae prexent in each of the lakes. Each approach was nessecary, allowing for a different aspect of the lgal community to be examined.

Chapter 7

Periphyton in Loughs Atedaun, Cullaun and Inchiquin

In this chapter the periphyton algal assemblages from the littoral area of each of the study lakes are examined. Changes in the periphyton communities over a ten month period from January to October 2005 are outlined. Firstly a general discussion of the different species found is presented in terms of the composition and species richness of the periphyton samples as well as identifying the most abundant species in each sample. Species diversity indices are then used to examine community and species changes within each of the lakes.

7.1 Composition and abundance of the periphyton community

A total of 137 species were identified from the three lakes, 37 of these were Chlorophytes, 45 Cyanophytes and 45 Bacillariophytes. In Lough Atedaun 95 species were identified and this group comprised 24 Chlorophytes, 36 diatoms and 35 Cyanophytes. In Lough Cullaun 85 different species were identified, of which 19 were Chlorophytes, 40 diatoms and 26 Cyanophytes. In Lough Inchiquin 83 species were identified, 16 Chlorophytes, 34 diatoms and 33 Cyanophyte species (see Appendix 7 for complete species list and monthly counts). No species from other algal groups were found in these samples. Several types of unidentified cells were found, these were single cells < 10μm, single celled diatoms < 10 μm, filaments < 5 μm in width as well as some unidentified colonies. Difficulties occurred with small single celled algae and thin Cyanophytes as well as some clustered colonies where clear cell structure was not visible.

A seasonal cycle was evident in each lake with regard to the most abundant of the different phyla; though overall the diatoms were the most abundant phyla on the highest number of occasions followed by the Cyanophytes and then the Chlorophytes (Figure 7.1).

In Lough Atedaun the diatoms had the largest number of cells followed by the Cyanophytes and the Chlorophytes. During winter and early spring the diatoms were most abundant, while they were less prominent during summer and autumn. The Cyanophytes had low abundances in February, increased in March and remained quite constant until their annual maximum in September and decreased considerably after this

in October. The Chlorophytes had low cell abundance values during spring but increased during early summer. In mid-summer Chlorophyte abundances decreased but began to increase again in September.

From Figure 7.2 it is evident that in January in Lough Cullaun the diatoms had the lowest share of cell abundance compared to the Cyanophytes and Chlorophytes. By February the cell abundance of Cyanophytes and especially diatoms had increased while the number of Chlorophytes decreased dramatically. In March the number of diatoms increased whilst the number of Cyanophytes dropped sharply. Chlorophyte and Cyanophyte abundances did not increase again until summer with Chlorophyte cell numbers peaking in June. At this point the number of diatoms began to decrease. In July a similar number of Chlorophytes and diatoms were identified. The Cyanophytes reached their annual maximum in August concomitant with the diatoms reaching their annual minimum. Similar numbers of diatoms and Cyanophytes were found in September with a lower abundance of Chlorophytes. In October diatoms increased whilst abundances for both other phyla decreased.

Diatoms dominated in Inchiquin (Figure 7.3) but to a lesser extent than in both other lakes. In January Chlorophytes had the lowest abundances while February saw Cyanophytes with the lowest level of abundance. A similar number of Chlorophytes and diatoms were identified in February. From March through to June diatoms decreased steadily whilst Chlorophyta increased. The Cyanophytes decreased until March but increased again from March until June and then had a slight drop in July before peaking in August. Chlorophytes were low compared to the other two phyla during summer and on into autumn. After August Cyanophyte values decreased quickly whilst diatoms decreased in September.

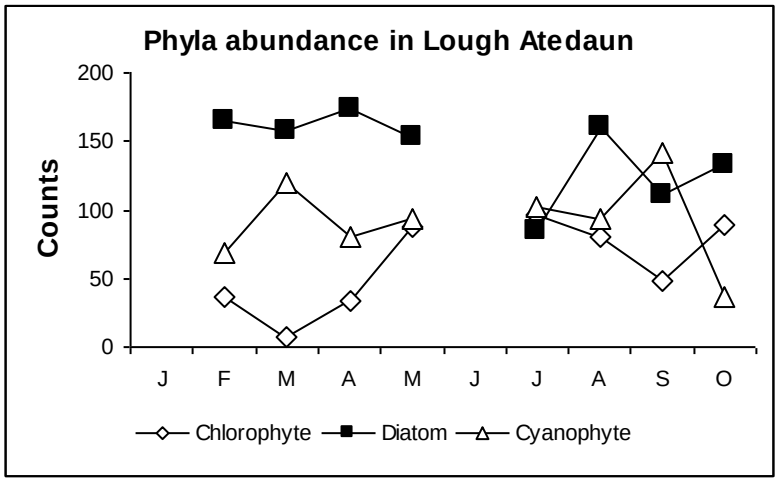


Figure 7.1 Phyla abundance in Lough Atedaun. No data for June 2004

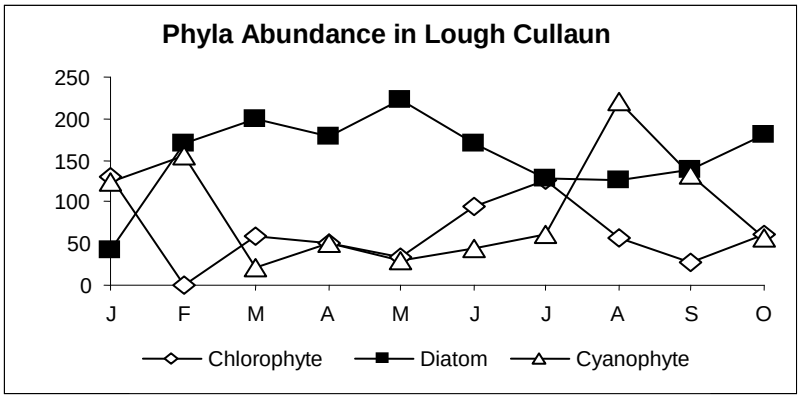


Figure 7.2 Phyla abundance in Lough Cullaun

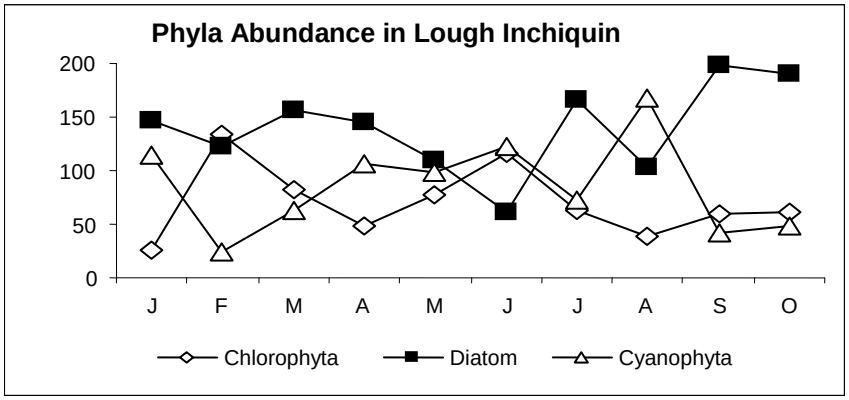


Figure 7.3 Phyla abundance in Lough Inchiquin

7.2 Species richness and the most abundant species

The total number of species (species richness) found in each sample changed on a monthly basis (see Figure 7.4). Species abundance curves for each sample highlight the four species with the highest relative abundance in rank order for each month and are shown in Figures 7.5, 7.6 and 7.7.

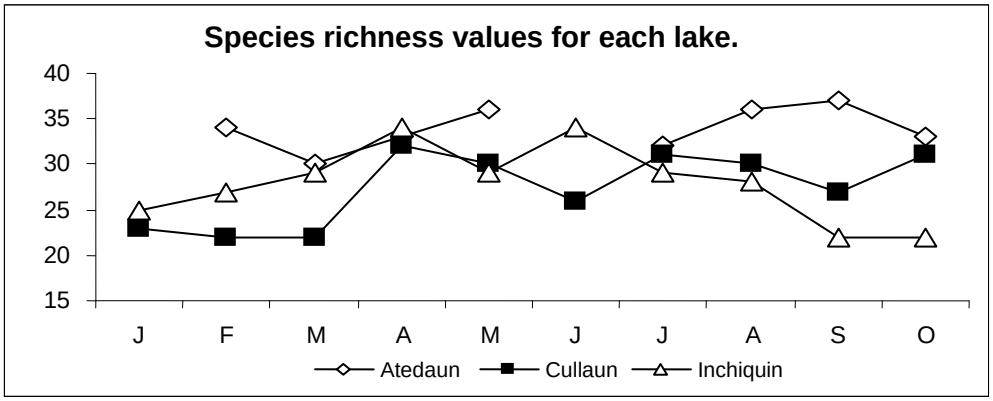


Figure 7.4 Species richness values for each lake. No data for January and June in Lough Atedaun

In Lough Atedaun the minimum species richness value was 30, which occurred in March, the maximum was 37 in September and the mean was 34. Species richness values for Lough Atedaun remained quite constant through out the year with very little change occurring between months. In Lough Cullaun the minimum species richness value occurred in March when 22 different species were identified. The maximum value of 32 occurred in April. I n Lough Cullaun a lower number of species were identified compared with both other lakes. A seasonal trend of low species richness in winter, increasing in April, before decreasing and then again rising in June. Species richness remains quite constant from this point onwards. In Lough Inchiquin a minimum value of 22 species occurred in September and October, a maximum value of 34 occurred in April and June whilst the mean species richness value was 28. Species richness peaked on two occasions in April and June. From January until April the number of species increased steadily then dropped after April and increased again until June. After June values decreased through summer and autumn remaining at an annual low during late autumn and early winter.

The most dominant species each month show two distinct patterns (Figures 7.5 to 7.7); the first is that in some months a single species dominated on its own, whilst the other more frequent pattern is that of several species co-dominating together. August, September and October were months where a single species tended to dominate in Atedaun (Figure 7.5). From February until July several species tended to co-dominate. In February the diatom *Gomphonema* and the Cyanophyte *Chroococcus* dominated followed then by two more diatoms *Navicula* and *Cymbella.* In March a filamentous Cyanophyte *Lyngbya* (> 10μm width) dominated with a relative abundance of 8 %, with three other diatoms co-dominating (*Gomphonema*, *Cymbella* and *Placoneis).* In April *Chroococcus* dominated although there were 3 diatoms with similar relative abundances co-dominating, these were *Gomphonema*, *Nitzschia* and *Tabellaria*. Just two species dominated in May these were *Scenedesmus* and *Chroococcus*. In July the colonial Chlorophyte *Stigeoclonium* dominated along with *Chroococcus* and two other small single celled diatoms *Achnanthes* and *Achnanthidium*. In August the diatom *Navicula* dominated with a relative abundance of 27 %, in September the Cyanophyte *Chroococcus* dominated (relative abundance 15%) and in October the Chlorophyte *Scenedesmus* dominated with a relative abundance of 25 %.

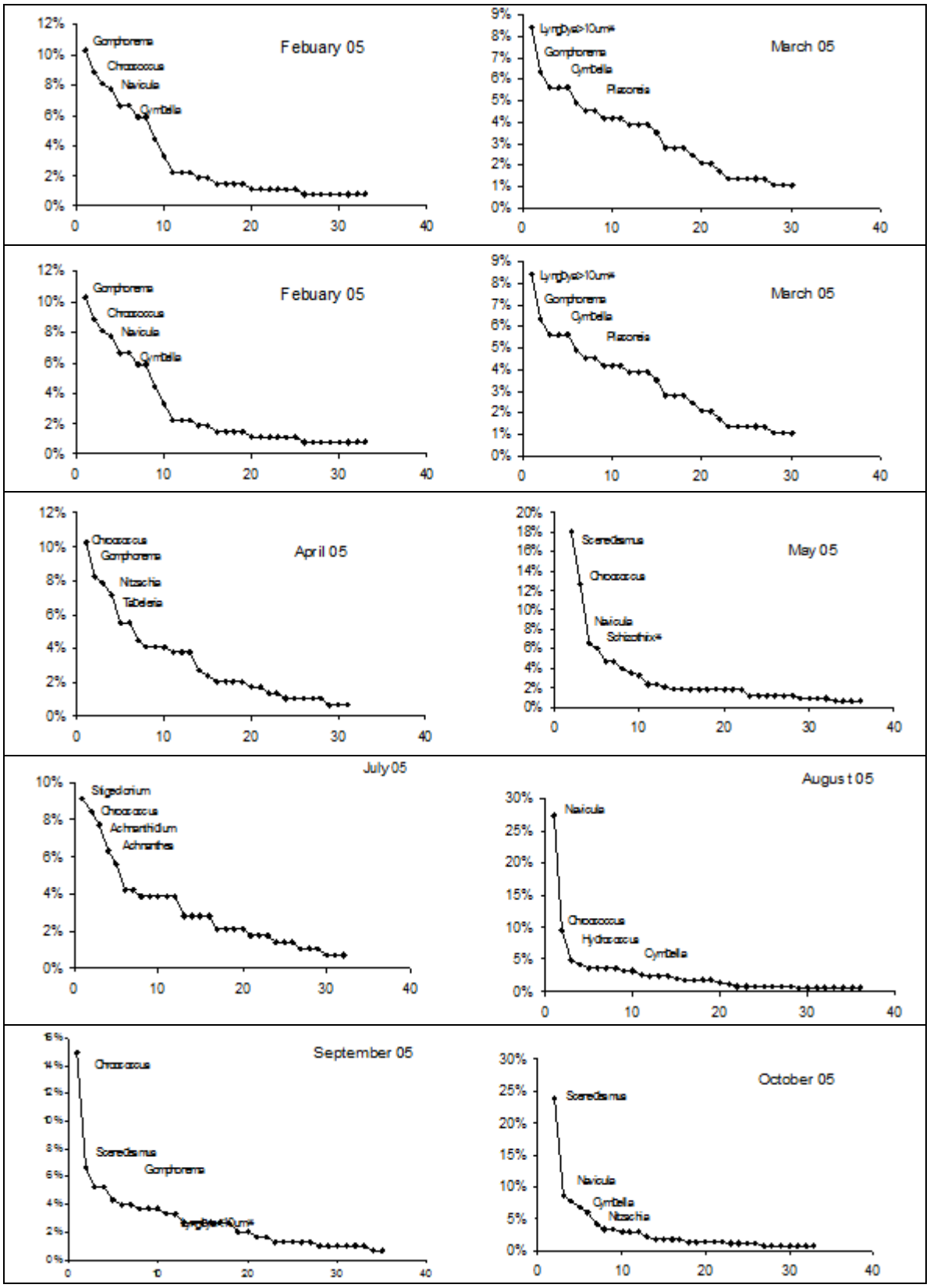
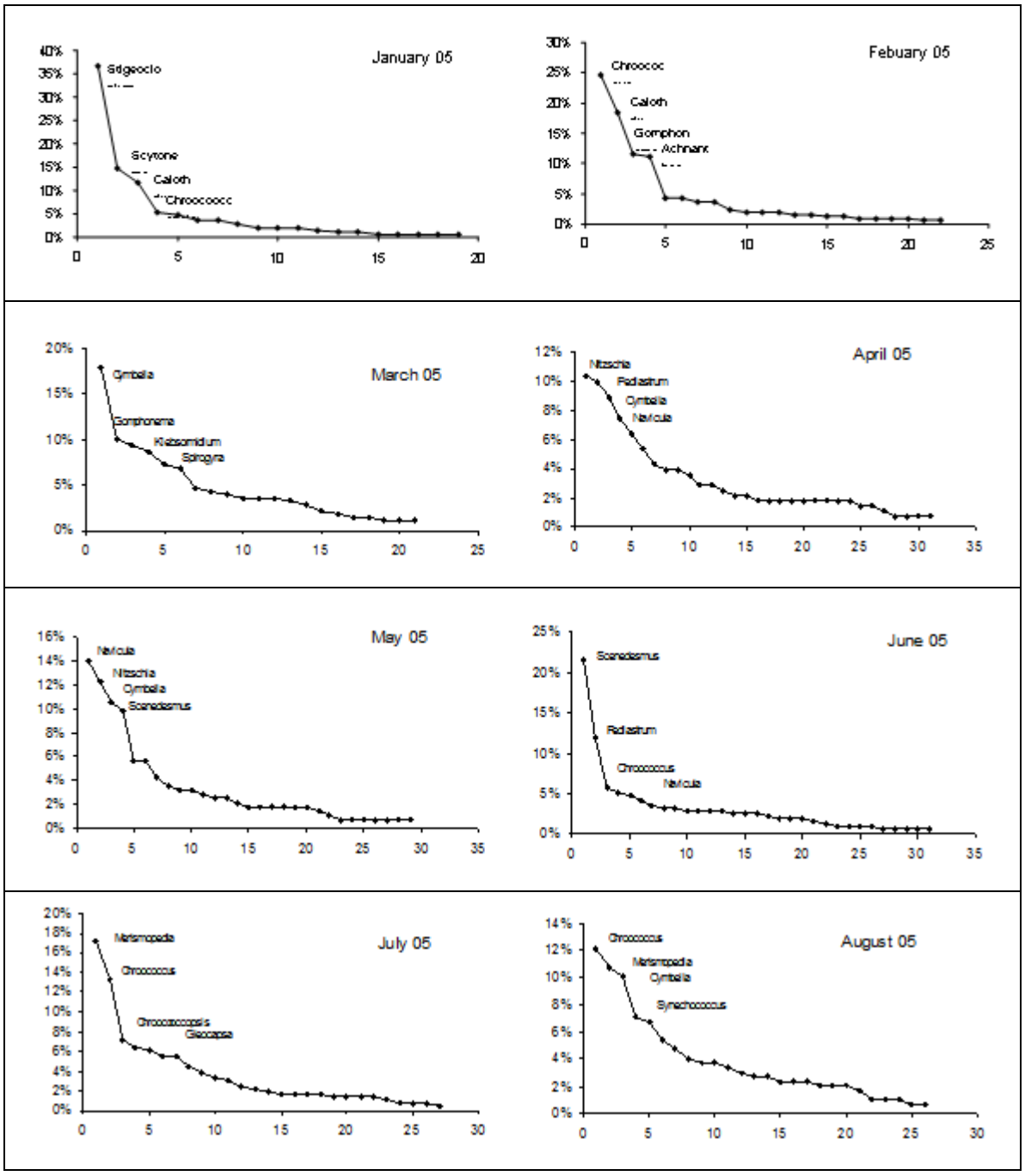

Febuary 05
Gomphonema
Chroococcus
Navicula
Cymbella
March 05
Lyngbya>10um*
Gomphonema
Cymbella
Planconeis
Febuary 05
Gomphonema
Chroococcus
Navicula
Cymbella
March 05
Lyngbya>10um*
Gomphonema
Cymbella
Planconeis
April 05
Chroococcus
Gomphonema
Nitzschia
Tabellaria
May 05
Scenedesmus
Chroococcus
Navicula
Schizothrix*
July 05
Stigeoclonium
Chroococcus
Achnanthidium
Achnanthes
August 05
Navicula
Chroococcus
Hydrococcus
Cymbella
September 05
Chroococcus
Scenedesmus
Gomphonema
October 05
Scenedesmus
Navicula
Cymbella
Nitzschia

Figure 7.5 Monthly algal species abundance curves from the open water sites in Lough Atedaun, X-axis is in rank order, and Y-axis is % relative abundance No data for June in Atedaun.



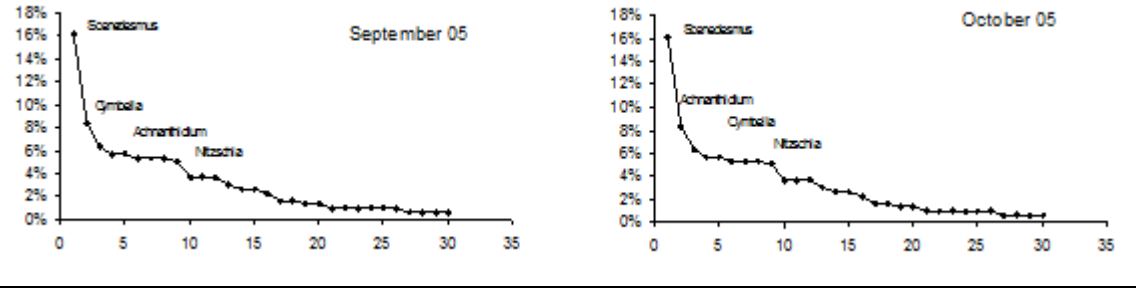
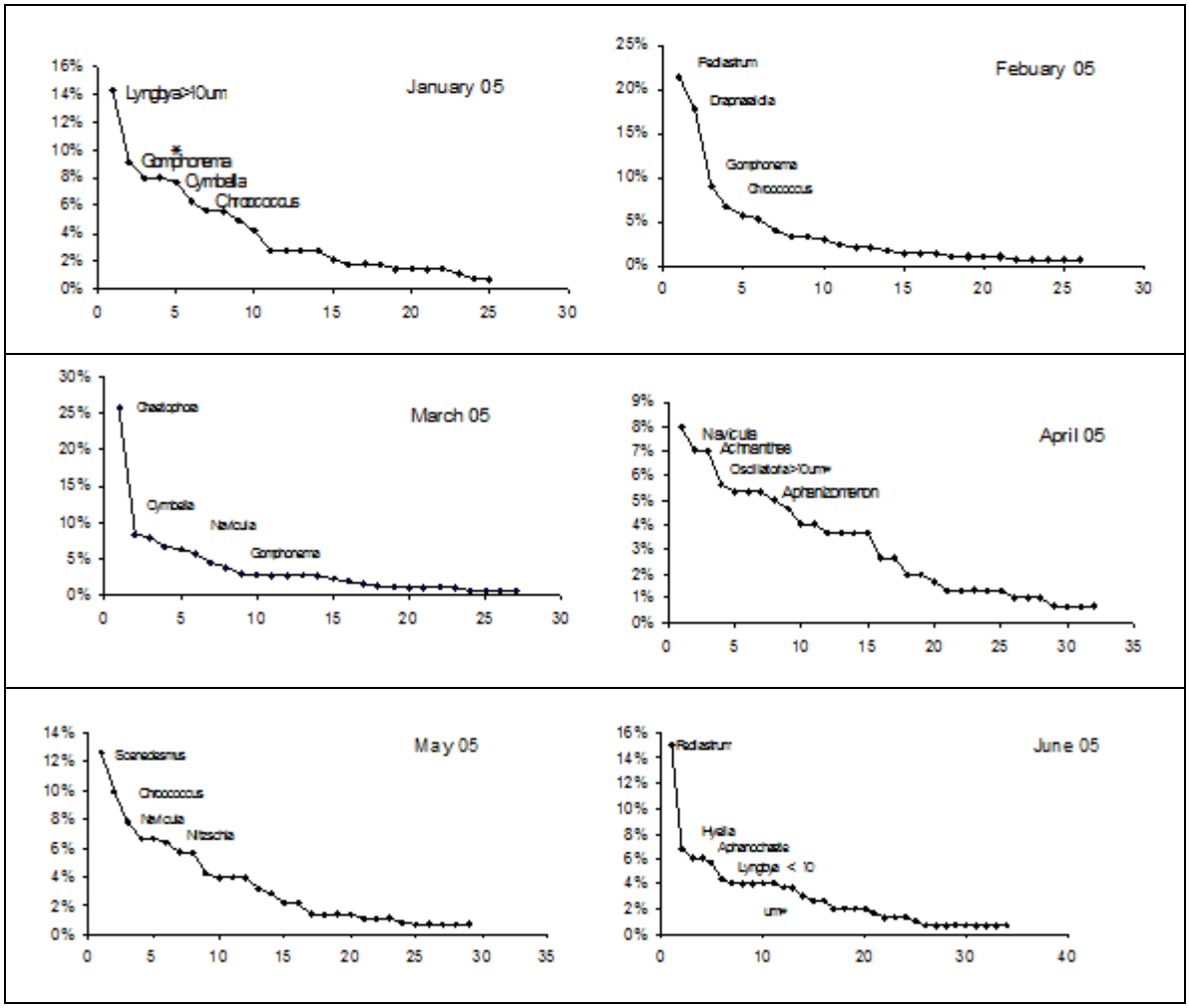


Figure 7.6 Monthly algal species abundance curves from the open water sites in Lough Cullaun, X-axis is in rank order, and Y-axis is % relative abundance.



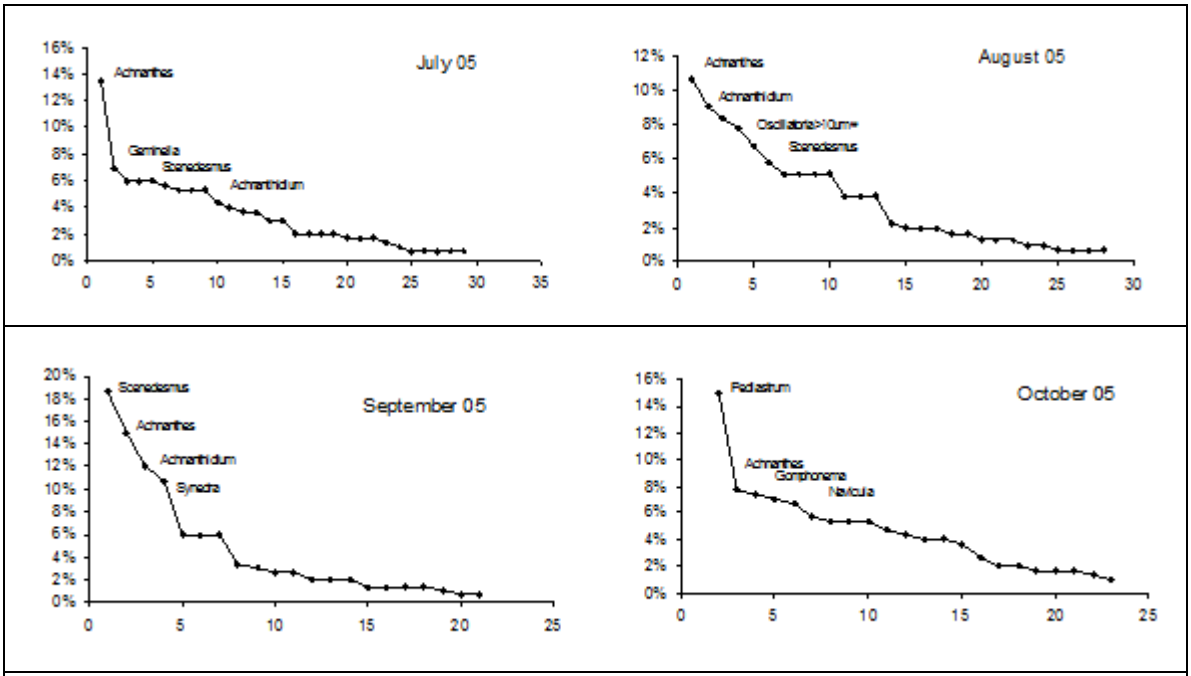


Figure 7.7 Monthly algal species abundance curves from the open water sites in Lough Inchiquin, X-axis is in rank order, and Y-axis is % relative abundance.

In Lough Cullaun in January and June a single species dominated, in January this was *Stigeoclonium* with a relative abundance of 37 % (Figure 7.6). In June *Scenedesmu*s was most abundant with a relative abundance of 22 %. The next most abundant algae were *Pediastrum* another Chlorophyte with a relative abundance of 12 %. In February two Cyanophytes had relatively high abundances these were (*Chroococcus* a single celled or colonial Cyanophyte and *Calothrix* a filamentous Cyanophyte). In March two diatoms *Gomphonema* and *Cymbella* were most abundant along with two filamentous Chlorophytes called *Klebsormidium* and *Spirogyra*. In April the algae with the highest relative abundance was *Cymbella* a diatom followed by *Pediastrum* a Chlorophyte. *Navicula* also dominated in May along with *Nitzschia* a similar shaped pinnate diatom. Two colonial Cyanophytes (*Chroococcus* and *Merismopedia)* were most abundant during July and August. In September and October *Scenedesmus* had the highest relative abundance.

In Lough Inchiquin a single algae was most abundant on four occasions, usually followed by several other algae with similar but lower relative abundances (Figure 7.7) values. The filamentous green algae *Chaetophoroa* dominated in March (relative abundance of 26

%). The colonial Chlorophyte *Pediastrum* had the highest relative abundance in Febuary, June and October. Another Chlorophyte *Scenedesmu*s had the highest relative abundance in May and September whilst the single celled diatom *Achnanthes* had the highest relative abundance in July and August. On only one occasion did a Cyanophyte have the highest relative abundance. This was in January when *Lyngbya* (width > 10μm) had the highest relative abundance.

In summary, the species abundance curves show that different algae predominated in each month in each lake e.g. single celled Cyanophyte *Chroococcus* in Lough Atedaun, the single celled pennate diatom *Cymbella* in Lough Cullaun and the colonial Chlorophytes *Pediastrum* and *Scenedesmus* in Lough Inchiquin. There is some overlap between lakes with algae such as *Scenedesmus* having a highest relative abundance in each lake on at least one sampling date though not on the same date. In most samples several species tended to co-dominate.

7.3 Diversity and structure of the periphyton community

The Shannon Weiner index and evenness values were used to examine the diversity and structure of the periphyton community in each lake. The minimum Shannon Weiner diversity values were found in Lough Atedaun in August (1.27), in Cullaun in January (0.98) and in Inchiquin in September (1.13). Maximum diversity was 1.43 in September in Atedaun, 1.37 in Cullaun and 1.41 in Inchiquin in April.

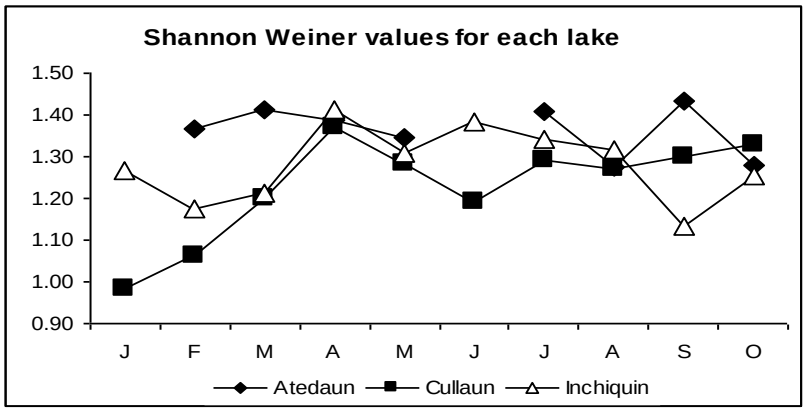


Figure 7.8 Shannon Weiner diversity for each lake. No data for Atedaun in January and

June 2004

Lough Inchiquin had a higher Shannon diversity than Lough Cullaun in January (no data for Atedaun). In Lough Inchiquin the most abundant species that month was *Lyngbya* while in Cullaun it was *Stigeoclonium*. A significant difference between the two lakes was that in Inchiquin there were eight species with a relative abundance > 5% whilst in Cullaun there were only four. February was the month with the greatest diversity differences between each lake. Atedaun had the highest diversity followed by Inchiquin then Cullaun. Cullaun had the lowest diversity with only nines species with a relative abundance > 2 % whilst there were 14 species in the Atedaun sample and 13 in Inchiquin. *Gomphonema* had the highest relative abundance in Atedaun and the third highest in Cullaun and Inchiquin. Though Atedaun and Inchiquin had a similar number of species with a relative abundance > 2%, the different Shannon index values were a result of the different species richness values (12 more in Atedaun). Again in March Atedaun had the highest diversity with Inchiquin and Cullaun having similar species diversity. In Atedaun in March there were 21 species with a relative abundance > 2% whilst both other lakes had 15 species with a relative abundance of > 2%. The Cyanophyte *Lyngbya* was the most abundant species in Atedaun, the diatom *Cymbella* was the most abundant in Cullaun and the Chlorophyte *Chaetophora* was the most abundant in Inchiquin. Examination of the relative abundance graphs (Figures 7.5-7.7) show that the species *Cymbella*, *Lyngbya* and *Gomphonema* were commonly abundant in each lake on this date. It was also evident that there were species which were distinct to each lake such as *Klebsormidium* in Cullaun and *Navicula* in Inchiquin. In April each lake had similar species richness (c. 33), Shannon diversity (c. 1.41) and each lake had a similar number of species with a relative abundance > 2% (c. 17) and > 5% (c. 6). Almost all of the most abundant species in April were diatoms, though the species abundance graphs show that differences did occur between which diatom species were most abundant. In May diversity values were similar for each lake and lower than the previous month. For the first time the species *Scenesdesmus* is evident in the most abundant species in each lake. In Atedaun and Inchiquin *Scenesdesmus* was the most abundant species while the diatom *Navicula* was the most abundant species in Cullaun. Inchiquin had higher diversity than

Cullaun in June (no data exists for Atedaun). In both lakes on this date a single Chlorophyte species dominates, *Scenedesmu*s in Cullaun and *Pediastrum* in Inchiquin. In July each lake had similar species diversity but differences occurred regarding which species were most abundant. A similarity between each lake at this time of year was the presence of Cyanophytes as one of the four 4 most abundant species (particularly *Chroococcus)*. In September Atedaun had the highest diversity followed by Cullaun and Inchiquin. *Scenedesmus*, *Achnanthes* and *Achnanthidium* were some of the most common species in the lakes at this time of year. A large difference occurred between Inchiquin and the other two lakes in terms of the number of species with a relative abundance > 2% on this date. Only eleven species had a relative abundance > 2% in Inchiquin in September whilst there were 20 in Cullaun and 18 in Atedaun. A similar trend occurred again between lakes in October with a mixture of Chlorophytes and diatoms dominating in each lake. A high relative abundance of *Scenedesmus* and the diatom *Achnanthes* was found in all autumn periphyton samples.

The evenness values for periphyton assemblages on each sampling date are shown in Figure 7.9. Months where high evenness occurred such as in Atedaun in March and July and Inchiquin in October were months with a very even distribution of species within the samples. January's samples from Lough Cullaun and Inchiquin differed due to the difference in relative abundance values of the most abundant species; *Stigeoclonium* had a relative abundance of 37 % in Cullaun, whilst *Lyngbya* had a relative abundance of 16% in Inchiquin. Samples with single species being most abundant with a low relative abundance tended to have low evenness values. But samples with a high number of species with relative abundance values > 2% and 5% tended to have high evenness values. Samples dominated by a single species occurred in August and October in Atedaun and had low evenness values (Figure 7.7). Samples taken in January, February, June and July in Cullaun had low evenness values. In Lough Inchiquin in February and March only one species had a relative abundance > 20 %, this was *Pediastrum* in February and *Chaetophora* in March.

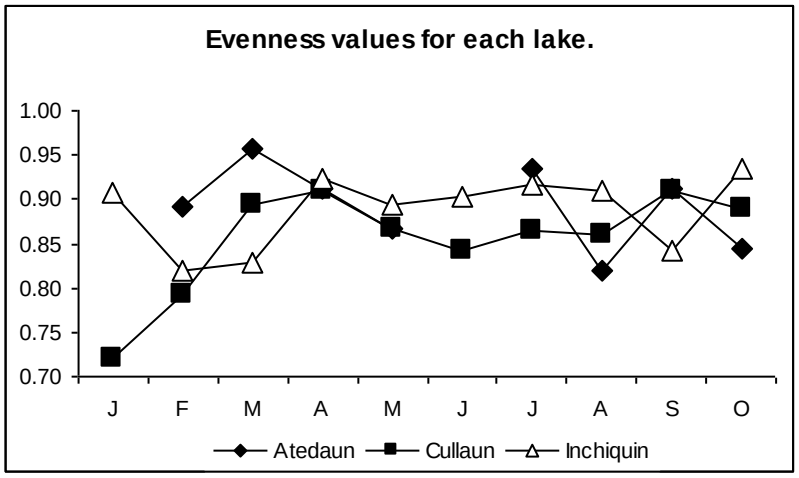


Figure 7.9 Evenness values for each lake. No data for January and June in Atedaun

7.4 Summary

Analysis of periphyton and phytoplankton showed that some overlap did exist between both sampling approaches. A large number of species were identified 137 in total and these were from 3 distinct genus.Though it wa also evident that entirely different algal species exist in the littoral areas of lakes compered to open water areas. This examination has described the species composition of the periphyton communities and showed monthly and seasonal changes associated with temperature. From these three lakes it is evident that almost all of the periphyton species are from the Bacilliarophyte, Chlorophyte or Cyanophyte. It is also obvious that certain species prefer certain lake types because although there was a lot of similarity in the types of species found in each lake, there were also a number of differences especially regarding species richness, dominant species and the composition and distribution of species within each lake.

Chapter 8

Relationship between Phytoplankton and Environmental variables

Physico-chemical variables and phytoplankton assemblages were examined for each lake in chapters 5 and 6. The aim in this chapter is to examine how the environmental variables relate to one another and determine overall temporal and spatial influences on the algal populations via ordination analysis.

8.1 Exploratory data analysis

Frequency histograms were plotted for each of the 12 environmental variables (Figure 8.1). Several variables showed a skewed distribution and required transformation. Q-Q plots were created in XLSTAT 2006 (not illustrated) and enabled decisions on whether log_{10} or square root transformation was best. Environmental data were transformed in order to reduce the influence of extreme data prior to multivariate analysis. This resulted in conductivity, alkalinity, NO_3-N, secchi depth, water level variation (WLV) and rainfall being square root transformed. Water depth was log_{10} transformed and chlorophyll-*a*, TP and DMRP were Log_{10} (+1) transformed, whilst pH needed no transformation. Algal species data were square root transformed.

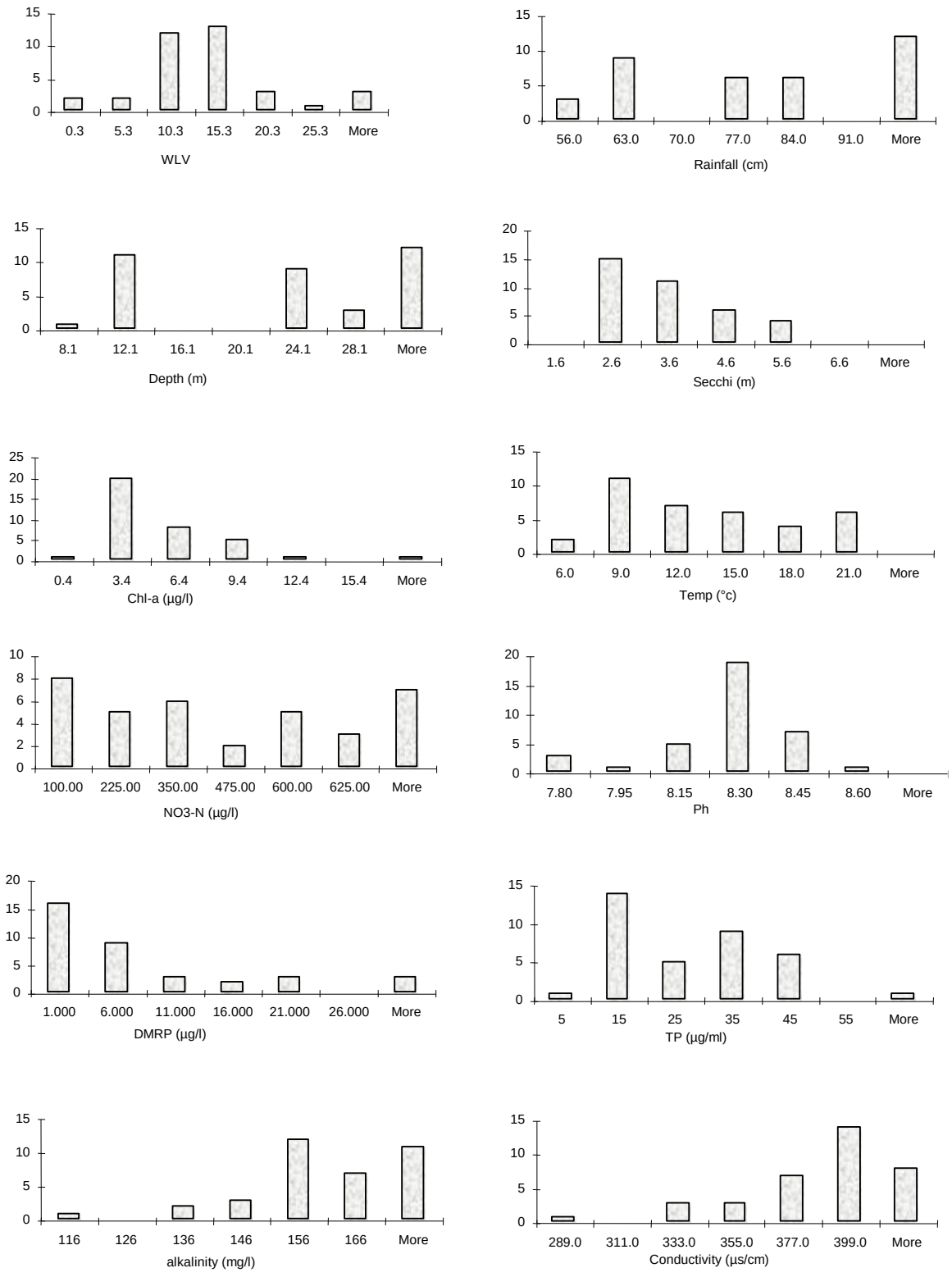


Figure 8.1 Frequency histograms of 12 environmental variables

The environmental variables were examined using Pearsons Correlation to see which of the variables were closely related and to determine which variables were exerting an influence upon each other. Pearson's product moment correlation coefficients were determined and are shown in Table 8.1. From Table 8.1 it is evident that conductivity had a strong positive correlation with alkalinity (r = 0.91) and $N0_3$-N (r = 0.77) and a negative correlation with temperature (r = -0.64). pH had a negative correlation with water level variation (WLV) (r = -0.62) and positive correlations with temperature (r = 0.54) and secchi depth (r = 0.54). Alkalinity is moderately correlated with NO_3-N (r = 0.56). DMRP's highest correlation occurred with $N0_3$-N (r = 0.69) and TP (r = 0.59). NO_3-N was highly negatively correlated with temperature (r = -0.75). The most important relationships identified in correlation analysis are discussed in more detail in ordination analysis in the next sections.

Table 8.1 Results of product moment correlation coefficients (r), between each of the measured environmental variables based on all monthly samples from each lake

Cond	1.00											
pH	-0.26	1.00										
Alk	0.91	-0.29	1.00									
DMRP	0.27	-0.40	0.13	1.00								
TP	-0.16	-0.11	-0.24	0.59	1.00							
NO3-N	0.77	-0.38	0.56	0.69	0.31	1.00						
Chl-a	-0.20	0.21	-0.14	-0.28	0.17	-0.13	1.00					
T°C	-0.64	0.54	-0.47	-0.40	0.00	-0.75	0.27	1.00				
Secchi	0.07	0.54	0.10	-0.27	-0.67	0.02	-0.22	0.02	1.00			
Depth	0.27	0.05	0.27	0.35	0.08	0.28	0.10	-0.01	0.28	1.00		
Rainfall	-0.15	0.09	-0.18	-0.07	0.11	-0.15	0.00	0.34	-0.42	-0.48	1.00	
WLV	0.01	-0.62	0.17	0.20	0.03	0.08	-0.02	-0.43	0.02	0.02	-0.34	1.00
	Cond	**pH**	**Alk**	**DMRP**	**TP**	**NO3-N**	**Chl-a**	**T°C**	**Secchi**	**Depth**	**Rain - fall**	**WLV**

8.2 Ordination analysis of the physico-chemical variables

Principal Components Analysis (PCA) was applied to explore the physical and chemical data simultaneously with date of sampling. Twelve environmental variables measured on a monthly basis in three lakes were included in the analysis (n = 432). In PCA all the

environmental data is summarised and best explained by a few underlying axes of variation. Prior to analysis data were transformed as described in the previous section. PCA analysis showed the first two axes to be the most important axes in capturing variation in the data set (Table 8.2). Axis 1 has an eigenvalue (λ_1) of 0.359, accounting for 35.9 % of the variance of the environmental data, while the axis 2 captured 15.7 % (λ_2 = 0.256). The first two axes explained 51.6 %. The first axis is highly correlated with alkalinity, conductivity and temperature (see PCA biplot in Figure 8.2) and biplot scores for these variables were the highest for the first axis. The second axis is highly correlated with rainfall, conductivity and alkalinity. Sample codes used in the PCA biplot are listed in Table 8.3.

Table 8.2 PCA of environmental variables based on all samples taken from Loughs Atedaun, Cullaun and Inchiquin

Axes		**1**	**2**	**3**	**4**	**Total variance**
Eigenvalues	:	0.359	0.256	0.204	0.100	1.000
Cumulative (%) variance of species data	:	35.9	61.6	82.0	91.9	
Sum of all eigenvalues						1.000

		Axis 1	**Axis 2**
	Eigenvalues	0.3594	0.2562
1	Conductivity	-0.7366	-0.6399
2	pH	0.4717	-0.2442
3	Alkalinity	-0.7764	-0.4867
4	DMRP	-0.1949	-0.0600
5	TP	0.2465	-0.0091
6	NO3- N	-0.5888	-0.4647
7	Chl-a	0.3544	0.2818
8	Temp	0.6849	0.1314
9	Secchi	-0.3066	0.0855
10	Depth	-0.4610	-0.0445
11	H.W. M	0.6602	-0.2751
12	Rainfall	-0.5288	0.7142

In the PCA biplot (Figure 8.2) the environmental variable vector is equal to the rate of change within the variable from its weighted average for the data set located in the centre of the plot (0,0). The variables with longer vectors represent the most important

environmental variables (TerBraak, 1986, 1987). The angle between two environmental variable vectors represents the level of correlation between those two variables and it is clear from the ordination plot that several are closely correlated variables (Shaw, 2003). The variables conductivity, alkalinity, and NO_3-N have the longest vectors and are closely clustered. Alkalinity and conductivity would be expected to be closely correlated as these measurements indicate the amount of ions within the water. TP, Chlorophyll-*a* and temperature are also close together and negatively correlated with secchi transparency, water depth and DMRP. The close correlation of chlorophyll-*a* and temperature is well known with increases in temperature promoting algal production. The small angle between TP and temperature also indicates a close positive correlation. As expected rainfall and WLV (water level variation) are positioned in opposite biplot quadrants indicating a negative correlation. pH is highly correlated with WLV.

From the PCA ordination plot in Figure 8.2 the influence of sample month on the environmental variables is evident (see Table 8.3 for sample codes). The closer a sample position is to an environmental vector then the greater the influence on that variable. There was a general seasonal trend regarding the distribution of samples. Most of the samples taken in the winter of 2004 (1 - 3) are co-located in the top left of the plot while samples taken in the autumn of 2005 (4 - 6) are co-located in the top right of the plot. Spring samples (7 - 9) are generally located in the bottom left quadrant and summer samples (10 - 12) tend to locate in the bottom right quadrant. Samples taken during warmer months were strongly influenced by nutrients and temperature. A distinct group of spring and early summer samples (mostly from Lough's Inchiquin and Atedaun with just one sample from Lough Cullaun) are located along the second axis. The absence of Cullaun samples reflect the oligotrophic nature of this lake with low nutrient levels. Many of the August and September samples (from Lough's Atedaun and Inchiquin) were positioned along the Chlorophyll-*a* vector, a variable directly affected by temperature.

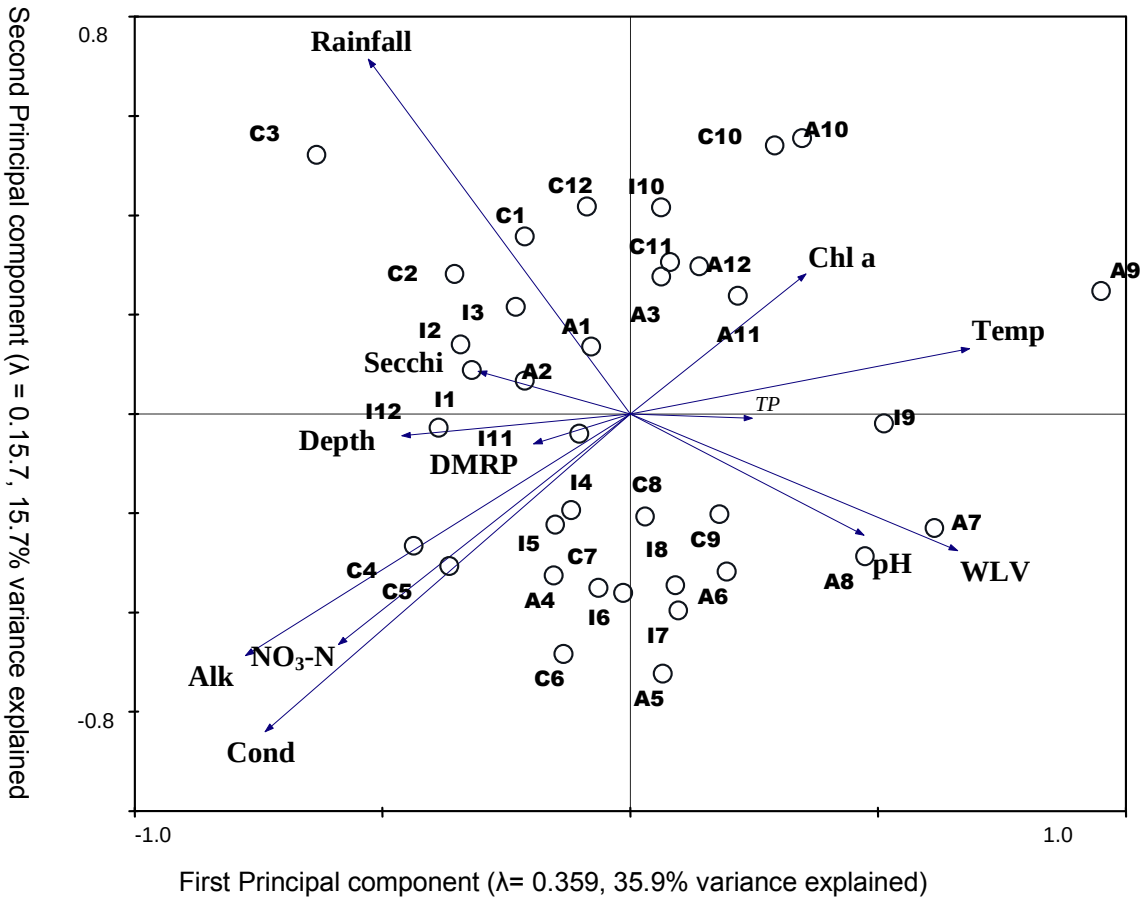


Figure 8.2 PCA biplot of physico-chemical data collected on a monthly basis from Atedaun, Cullaun and Inchiquin. See Table 8.2 for identification of sample codes

Table 8.3 Sample codes representing monthly sample dates in each of the lakes

Sampling Month	Atedaun	Cullaun	Inchiquin
November 2004	A 1	C 1	I 1
December 2004	A 2	C 2	I 2
January 2005	A 3	C 3	I 3
February 2005	A 4	C 4	I 4
March 2005	A 5	C 5	I 5
April 2005	A 6	C 6	I 6
May 2005	A 7	C 7	I 7
June 2005	A 8	C 8	I 8
July 2005	A 9	C 9	I 9
August 2005	A 10	C 10	I 10
September 2005	A 11	C 11	I 11
October 2005	A 12	C 12	I 12

8.3 Ordination analysis of phytoplankton data

The DCA gradient length produced from the algal cell count data set was 3.062 and 3.749 for the biovolume data set. As the gradient length for both values was between 3 and 4, a unimodal response model is a better choice for multivariate analysis (Lepš & Šmilauer, 2003). Correspondence Analysis (CA) (indirect gradient analysis) was therefore used to explore the structure of the algal communities and Canonical Correspondence Analysis (CCA) (direct gradient analysis) were used to explore the relationship between the algal communities and the environmental variables.

8.3.1 Indirect Gradient Analysis

CA (Correspondence Analysis) was carried out on both cell count data and cell biovolume data. Eigenvalues for the first and second CA axes of the cell counts are 0.420 (λ_1) and 0.316 (λ_2), explaining 11.2% and 8.3 % (19.5 % cumulatively) of the total variance of the phytoplankton data (Table 8.4). Eigenvalues for the first and second axis of the phytoplankton biovolume data are 0.441 (λ_1) and 0.334 (λ_2), explaining 11.7 % and 8.9% (20.6% cumulatively) of the total variance of the phytoplankton data (Table 8.5). No major difference was found between relative cell abundance and biovolume data in terms of variance explained. A major difference is evident when both data sets were plotted in CA ordination diagrams, with the distribution of species and samples being very different in both diagrams. Separate species and sample ordination plots are shown for data sets in Figures 8.4, 8.5, and 8.6, in order to aid interpretation. Taxon codes used in the CCA figures are detailed in Appendix 8.

Table 8.4 Summary statistics of CA on phytoplankton cell count values.

Axes	**1**	**2**	**3**	**4**	**Total inertia**
Eigenvalues	0.420	0.316	0.296	0.265	3.768
Cumulative (%) variance of species data	11.2	19.5	28.9	34.4	
Sum of all eigenvalues					3.768

Table 8.5 Summary statistics of CA on phytoplankton cell biovolume values.

Axes	**1**		**2**	**3**	**4**	**Total inertia**
Eigenvalues	0.441		0.334	0.290	0.149	3.766
Cumulative (%) variance of species data	11.7	20.6	28.3	32.2		
Sum of all eigenvalues						3.766
Axes	**1**		**2**	**3**	**4**	**Total inertia**

CA ordination analysis of phytoplankton cell count species and sample data is displayed in Figures 8.3 and 8.4. Species in the CA biplot (Figure 8.4) exhibit a triangular pattern within the ordination plot. Sample A3 from Atedaun in January is separate from the main cluster of sites and is dominated by diatom species *Cymbella*, *Achnanthidium* and Navicula. The majority of sites and species are located along the first axis. The highest site scores along the first axis are from months 8 to 12 (June to October) in Atedaun and Inchiquin. At the opposite end of the axis are sample taken from Atedaun and Inchiquin in late winter and early spring. The separation of samples in to such distinct seasonal groups reflects the seasonal pattern of algal succession. Many of the monthly samples taken from Cullaun are located on the left hand side of axis 2; many of these samples are closely bunched together due to their similar species scores. At the right hand side of axis 1 are species associated with increased temperature and nutrient availability such as *Microspora* (species code 37), *Coelastrum* (17), *Monorophidium* (38), *Ulothrix* (61), *Tribonema* (60), *Euglena* (27) and *Aphanizomenon* (6). Negatively correlated with these species are species associated with late winter and spring such as *Synedra* (55), *Tetrastrum* (57), *Surirella* (54), *Gomphonema* (30), *Quadrigula* (47), and *Actinastrum* (3).

Results of CA of phytoplankton cell biovolume species and sample data is displayed in Figures 8.5 and 8.6. CA ordination analysis of phytoplankton biovolume samples and species resulted in the majority of samples and species being centred around the mean with outlier sites A3 (Atedaun, January) I1 (Inchiquin, November) and A1 (Atedaun, November). A3 is dominated again by diatom species plus *Oocystis* (41) while I1 and A1 are dominated by *Botrrycoccus* (9). *Botrycoccus* (9), as mentioned in Chapter 6 was found in colonial form. Biovolume values for *Botrycoccus* were the largest of all of the

species as seen in Table 6.9. Two other species with large biovolume values are *Staurastrum* (52) and *Dictyosphaerium* (23), the latter was also found in colonial form. Species which made similar contributions to total biovolume values are grouped closely together. This sees species grouped in terms of size and biovolume contributions and not in terms of phyla. This resulted in *Tolypothrix* (58), *Oscillatoria* (42), *Klebsormidium* (31), *Microspora* (37), *Cyclotella/ Stephanodiscus* (20), *Actinastrum* (3), *Tribonema* (60) and *Gomphonema* (30) all being grouped together, each making similar contributions to biovolume values. Another group closer to the mean but making similar Biovolume contributions were *Cymbella* (21), *Navicula* (39), *Achnanthes* (1), *Achnanthidium* (2) and *Oocystis* (41).

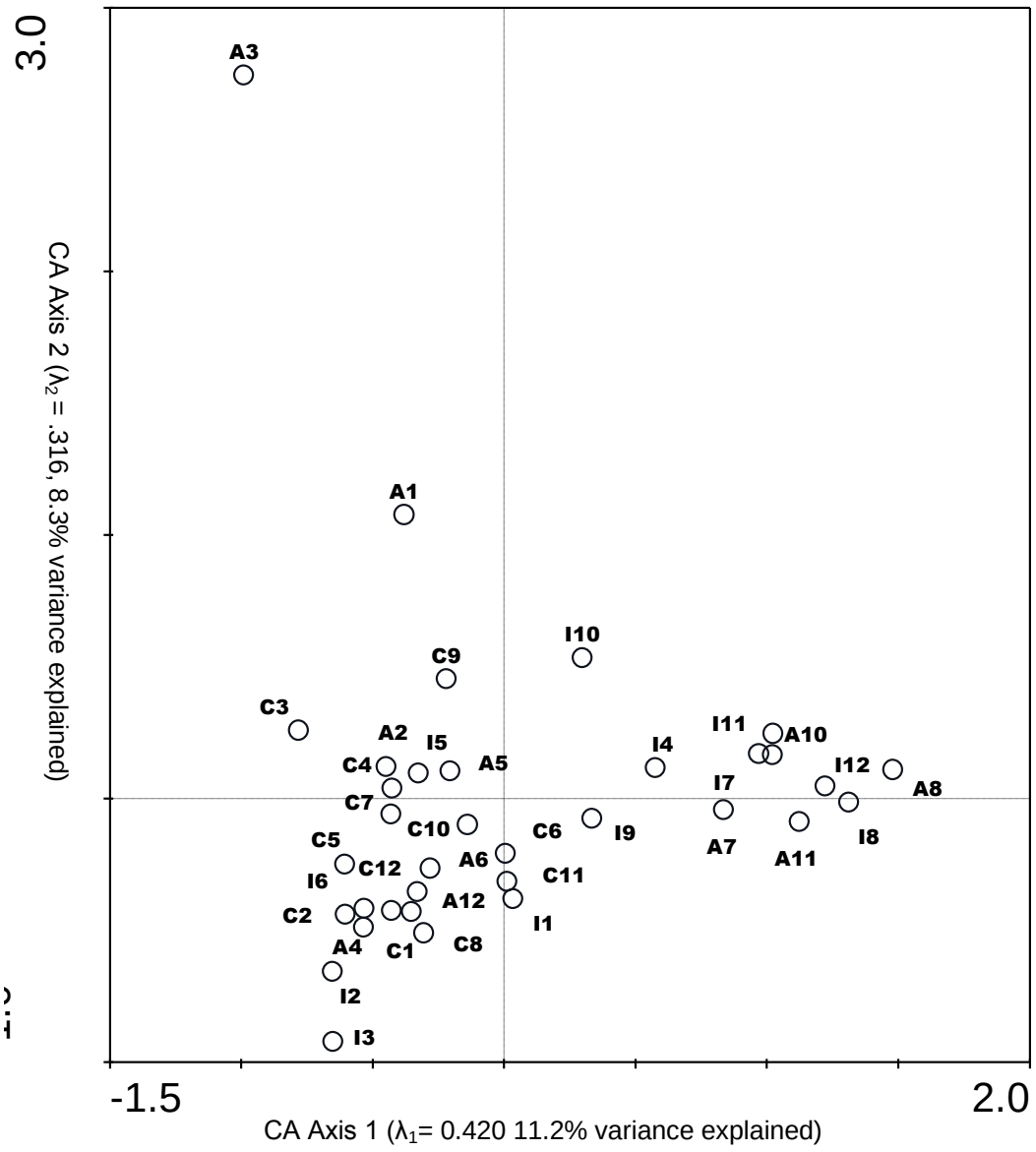


Figure 8.3 CA plot of site scores (sampling dates) of phytoplankton cell count data

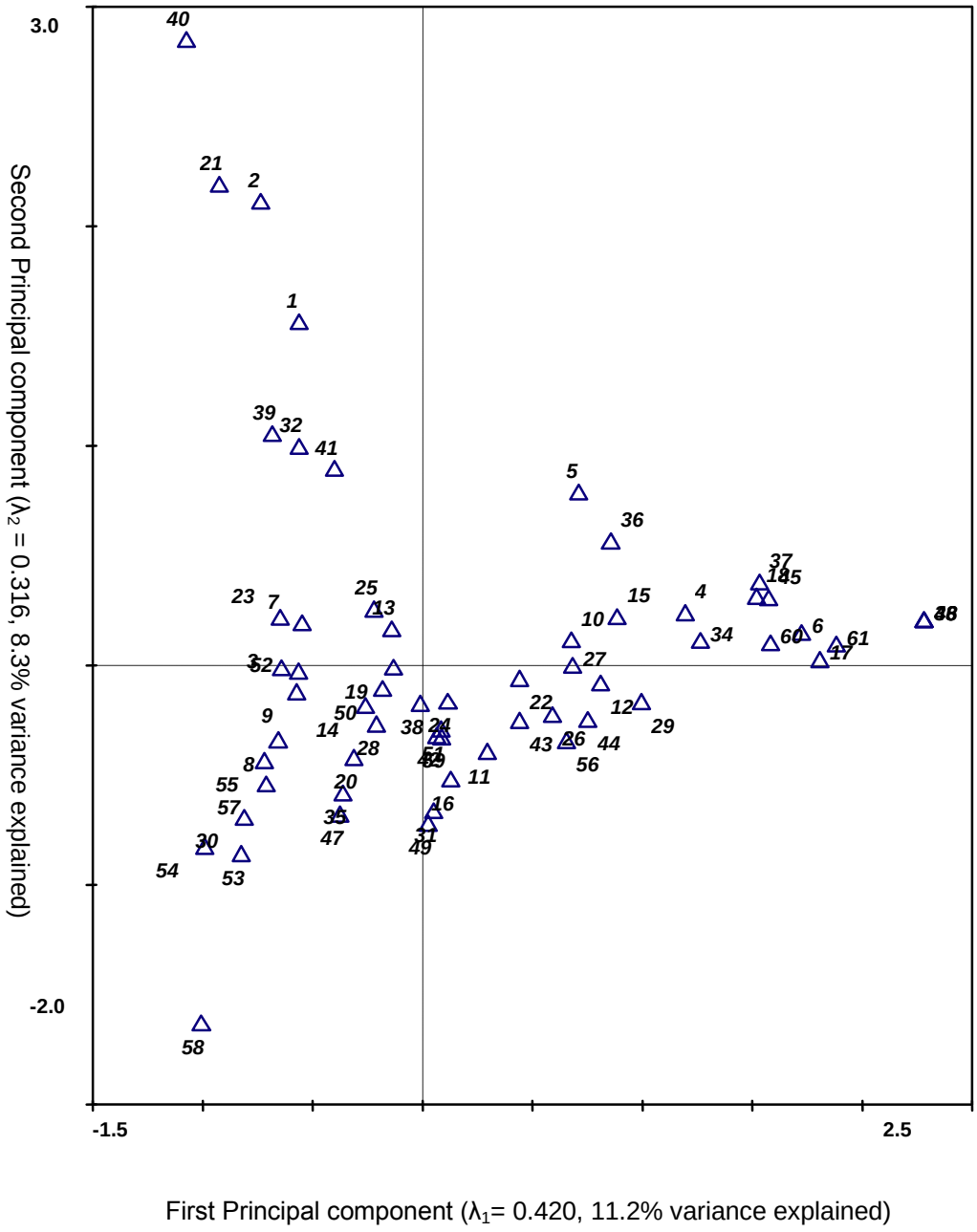


Figure 8.4 CA plot of species scores based on phytoplankton cell count data

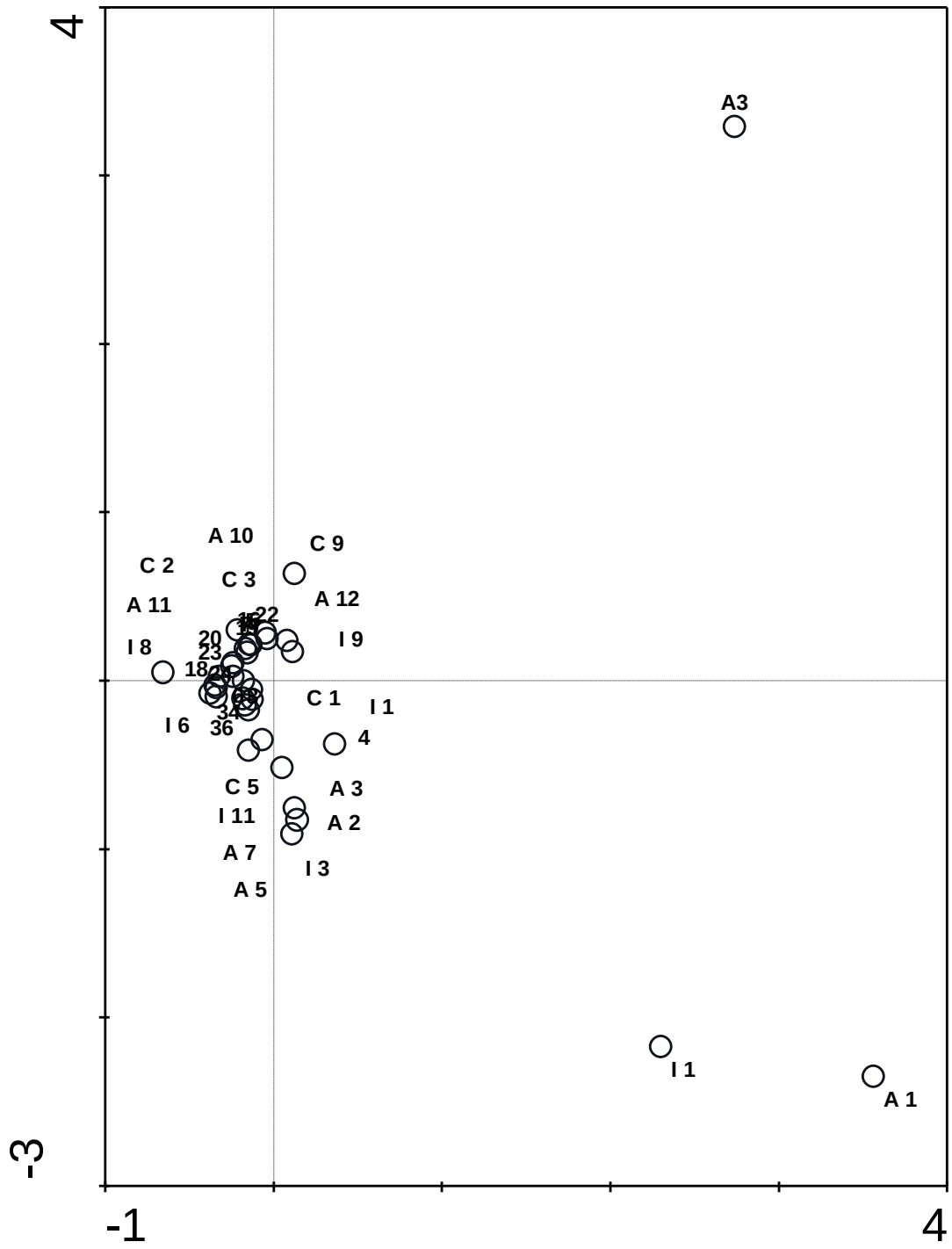


Figure 8.5 CA plot of site sample scores (sampling dates) of cell biovolume data

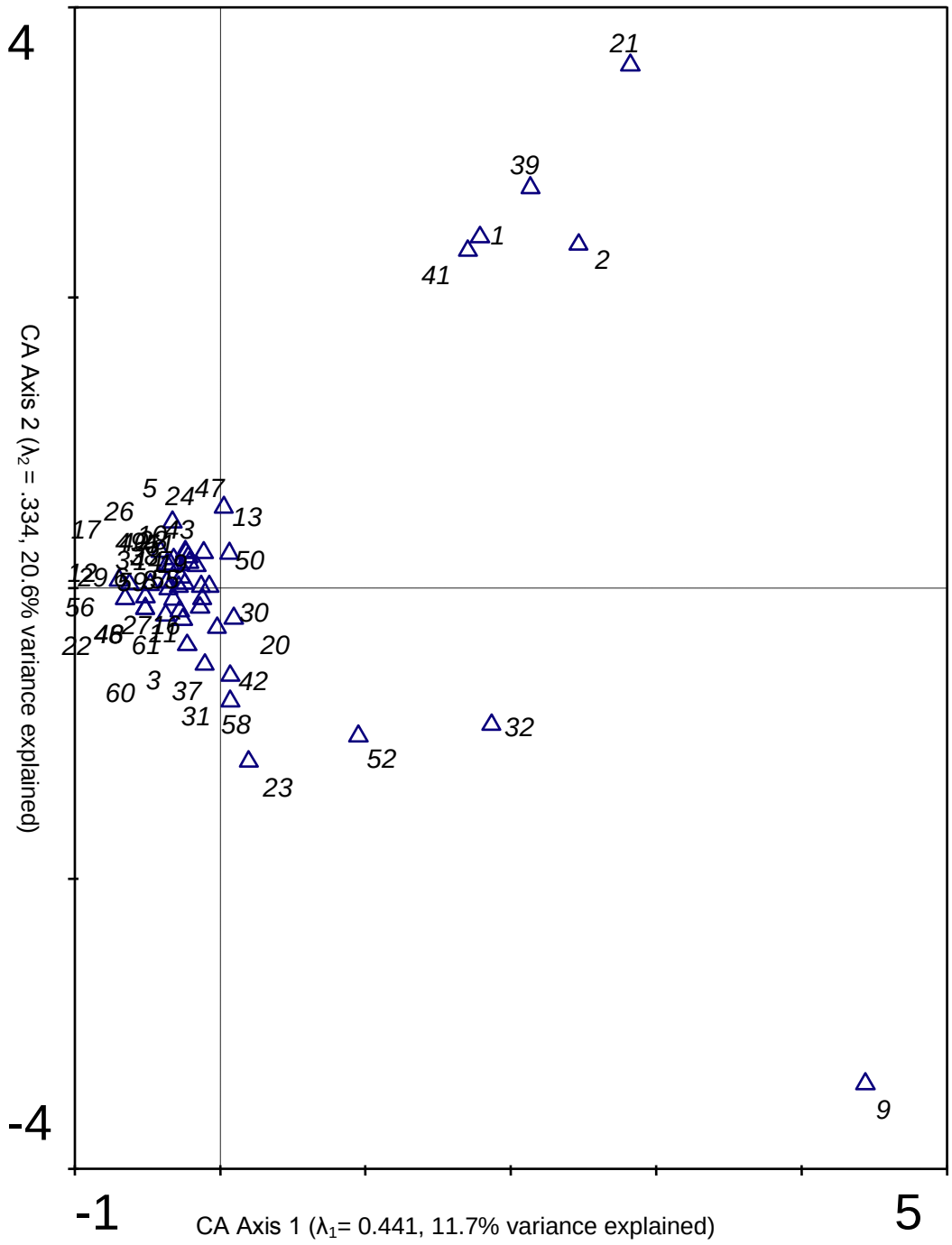


Figure 8.6 CA plot of species scores (species) of phytoplankton cell biovolume data

When CA ordination plots for the cell count and phytoplankton data are compared it is somewhat easier to interpret the cell count data. A seasonal pattern is evident with the cell count data a trend that was not as obvious in the biovolume ordination. CA of biovolume resulted in the majority of samples and species centred around the mean.

8.3.2 Direct Gradient Analysis

Canonical Correspondence analysis (CCA) is now used to try and understand the phytoplankton response when constrained by the environmental data to find a minimum combination of influencing factors which explain species variation. CCA has been used in this project to constrain the phytoplankton cell count and biovolume datasets with the 12 environmental variables. A CCA ordination can be produced as a triplot or biplot with study sites, phytoplankton taxa and environmental variables all located simultaneously within the one ordination diagram. CCA analysis was completed with Canoco 4.5 software. Species data were square root transformed and taxa were entered as codes as outlined in Appendix 8. Environmental variables were transformed and sampling dates were entered as numerical codes (listed in Table 8.3). Both algal data sets were scaled based on inter species differences, with the scaling type being biplot scaling. Monte Carlo permutation tests were conducted to test the significance of the CCA axes.

Eigenvalues and significance results for the cell count data are shown in Table 8.7 and the biovolume data in Table 8.8. The percentage variance explained by the first ordination axis is larger in the phytoplankton cell count data (0.334) compared with the biovolume data (0.277), while cumulative variance of the first four ordination axes account for 56.8 % in the cell count data and 60.4 % in the biovolume data. Total variance explained in both the cell count data and biovolume data are apparently similar (3.768 and 3.766 respectively). However, Monte Carlo significance tests show that the relationship between the environmental variables and phytoplankton cell biovolume data is not significant. The cell count data have a significance P-value of 0.080 for all ordination axes compared to a P-value of 0.1380 for the biovolume data. As a result further interpretation of the relationship between the environmental variables and phytoplankton will be carried out only using cell count data.

Table 8.6 Summary of CCA of phytoplankton cell count data constrained by 12 environmental variables

CCA Axes	**1**	**2**	**3**	**4**	**Total Variance**
Eigenvalue	0.334	0.202	0.177	0.156	3.768
Species Environment Correlation	0.934	0.890	0.868	0.899	
Cumulative (%) Variance of species –environment relationship	21.8	35.0	46.6	56.8	
Sum of all Eigenvalues					3.768
Monte Carlo significance	**Λ_1**	**F-ratio**	**P-Value**	**Trace**	**Permutations**
First axes	0.334	2.139	0.0020		499
All axes		1.253	0.0080	1.530	499

Table 8.7 Summary of CCA of phytoplankton biovolume data constrained by 12 environmental variables

CCA Axes	**1**	**2**	**3**	**4**	**Total Variance**
Eigenvalue	0.277	0.249	0.184	0.159	3.766
Species Environment Correlation	0.916	0.867	0.776	0.712	
Cumulative (%) Variance of species –environment relationship	19.2	36.5	49.3	60.4	
Sum of all Eigenvalues					3.766
Monte Carlo Significance	**λ_1**	**F-ratio**	**P-Value**	**Trace**	**Permutations**
First axes	0.277	1.749	0.466		499
All axes		1.136	0.138	1.441	499

CCA biplots of the phytoplankton cell count data and sites constrained by the 12 environmental variables are shown in Figures 8.6 (samples) and 8.7 (species). Constrained eigenvalues for the phytoplankton cell count data were 0.344, 0.202, 0.177 & 0.156, for axes 1 to 4, explaining 21.8%, 13.2%, 11.6% & 10.2% of the total variance of the algal assemblage. The first two axes accounted for 35% of the total variance of the algal data while axes 3 and 4 explained a smaller fraction of the total variance compared with the first two axes. The variables most strongly correlated with the first axis are temperature, WLV (water level variation) and chlorophyll-*a*, while the variables most strongly correlated with the second axis are TP, NO_3-N and DMRP (see Table 8.9). It was expected that temperature and chlorophyll-*a* would be closely correlated (as they also were in the PCA). Vector line length indicates that temperature has a greater affect on the phytoplankton assemblage than chlorophyll-*a*. Samples located at the left hand side of CCA axis 1 are characteristic of samples that are strongly influenced by temperature, chlorophyll-*a* and WLV. These are samples which were collected in summer in Atedaun and Inchiquin in months May to August (A7 –A10 and I7 – I10), all of which are composed of species closely associated with higher temperature values. On

the right hand side of CCA axis 1 samples are more closely associated with low temperatures, such as samples taken from Lough Cullaun between December and April (C2 –C6). Samples closely associated with high nutrient levels are located at the bottom of CCA axis 2. There is a distinct group of samples here, from Loughs Atedaun and Inchiquin (A2 –A6 and I2 –I6). These algal samples were all taken during the colder months (December through April) when nutrient levels were higher. At the other end of CCA axis 2 are samples taken during late summer and autumn when nutrient levels were at an annual low. It is also evident that samples from Loughs Atedaun and Inchiquin are following a similar pattern while samples from Lough Cullaun differ.

Table 8.8 Biplot scores of environmental variables from CCA analysis with phytoplankton cell count data from Loughs Atedaun, Cullaun and Inchiquin

		AX1	AX2	AX3	AX4
R (Spec, env)		0.9341	0.8896	0.8684	0.8992
1	Cond	0.3915	-0.4293	-0.3021	-0.0512
2	pH	-0.4109	0.0679	-0.3777	-0.4571
3	Alk	0.3407	-0.3058	-0.1221	0.0953
4	DMRP	0.2508	-0.6884	0.4087	-0.0498
5	TP	-0.3801	-0.7281	0.1828	0.2286
6	NO_3-N	0.4211	-0.6995	-0.0225	0.0023
7	Chl a	-0.4454	0.2432	0.0156	0.3910
8	Temp	-0.7773	0.3846	0.1567	-0.0647
9	Secchi	0.2623	0.5756	-0.0460	-0.5631
10	Depth	-0.0540	0.0814	0.3726	-0.6267
11	WLV	-0.4579	-0.3549	-0.1294	0.2809
12	Rainfall	0.3342	0.0227	0.5699	0.3545

The majority of species in the CCA biplot (Figure 8.7) are closely associated with the first axis which is influenced by changes in temperature, pH and chlorophyll-*a*. Species such as *Ankistrodesmus* (5), *Dinobryon* (24) and *Rhabdoglea* (49) all increased in abundance when temperature values increased. Many species of Cyanophyte were also positively associated with these variables e.g. *Aphanizomenon* (6), *Crucigenia* (18), and *Microcrocis* (36). The Euglenophyte *Eudorina* (26) is known to increases in abundance during warm periods and is closely associated with high TP levels along with *Trachlemonas* (59) and *Mallomonas* (34). Many of these species are associated with high WLV (or low summer water levels). *Chlamydomonas* (10), *Chlorella* (11), *Chroococcus*

(12), *Closteriopsis* (16) and *Oscillatori*a (42) are all located near to the TP vector line and therefore would be significantly affected by changes in this variable. The Cyanophyte *Tolypothrix* was located alongside the tip of the NO_3-N arrow showing a strong correlation between this variable and this species, other species located nearby are *Aphanothece* (7) and *Dictyosphaerium* (23). Closely correlated with high alkalinity and conductivity were many species of diatom e.g. *Achnanthes* (1), *Cyclotella/Stephanodiscus* (20), *Cymbella* (21), *Gomphonema* (30), *Neidium* (40), *Surirella* (54). This confirms what has been outlined in Chapter 5. Diatom species dominate to a far greater extent in Lough Cullaun an oligotrophic lake. In both other lakes these species tended to dominate during late winter and early spring, as seen in Figure 8.7. These species are negatively correlated with the temperature vector line. High rainfall levels are associated with species from the Cryptophyta group e.g. *Cryptomonas* (19), *Chroomonas* (14) and *Rhodomonas* (50). These species were seen regularly during the colder, wetter months. Increasing temperatures led to a reduction in the abundance of these species. This is something that was mentioned in Chapter 5 and is now supported by the results of the CCA analysis.

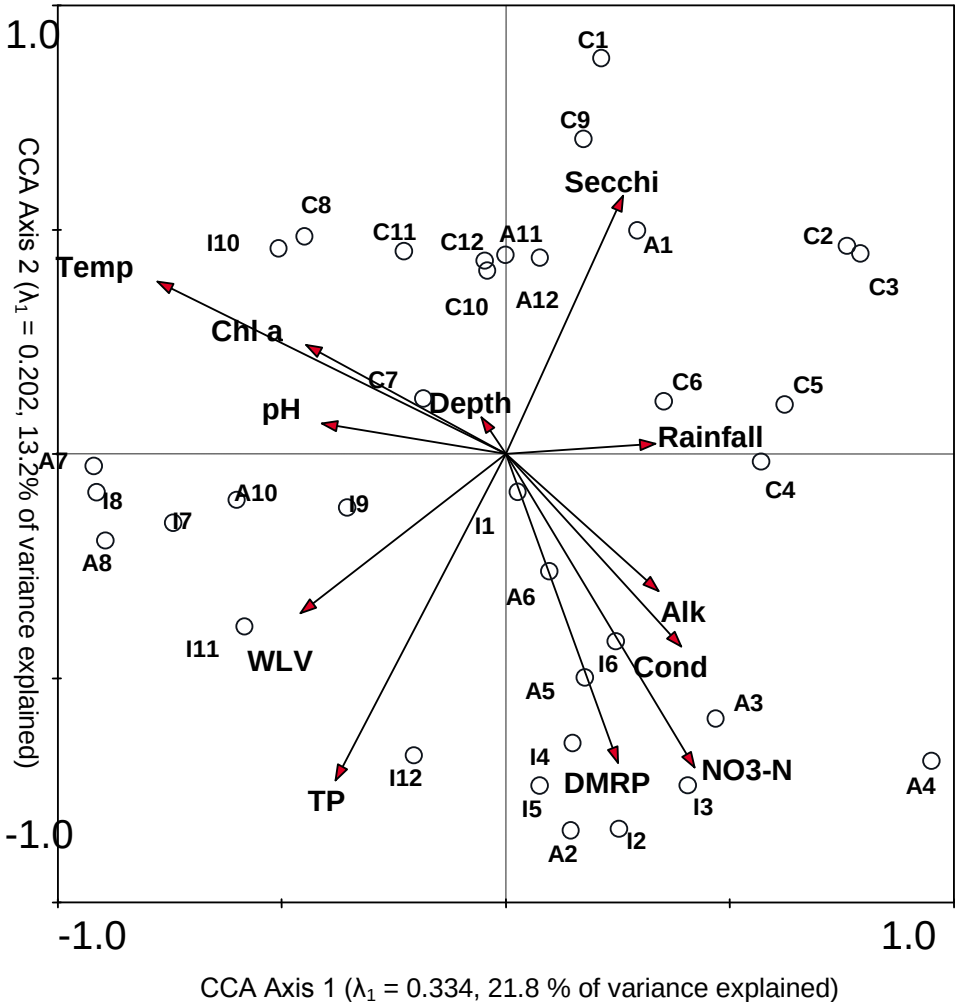


Figure 8.7 CCA sample biplot based on monthly phytoplankton cell counts and 12 environmental variables from Loughs Atedaun, Cullaun and Inchiquin. See Table 8.3 for sample codes (no data for A9 -sample misplaced)

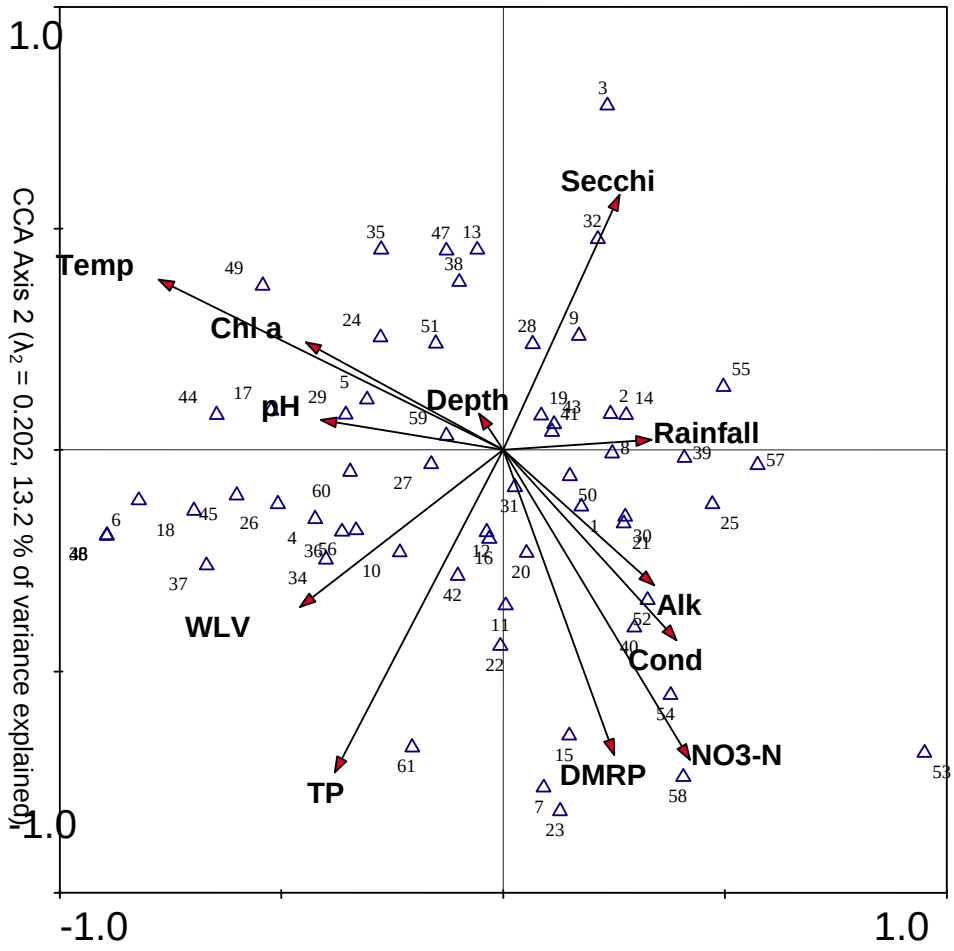


Figure 8.8 CCA species biplot based on monthly phytoplankton cell counts and 12 environmental variables Loughs Atedaun, Cullaun and Inchiquin (see Table 8.5 for species codes)

8.3.3 Comparison of unconstrained and constrained ordinations

When the CA (unconstrained) species and samples plots in Figures 8.4 and 8.5 are compared to the CCA (constrained) plots in Figures 8.6 and 8.7 many differences are apparent. Examination of CA and CCA species plots show that both plots have a different shape with many species having a different plot location. Some species such as *Chroococcus* (species code 12) and *Closteriopsis* (16) have moved only a small fraction whilst others species such as *Oocystis* (41) have moved a considerable distance. CA axes eigenvalues (Axis 1 0.420, Axis 0.316) were generally higher than the CCA axes (Axis 1 0.334, Axis 2 0.202) while percentage variance explained by the CA ordination axes (CA

Axis 1, 11. 2% and Axis 2, 8.3%) were generally lower that the CCA ordination axes (CCA Axis 1, 21.8% and Axis 2, 13.2%). The eigenvalue and % variance differences between ordinations implies that variation evident in the unconstrained phytoplankton data (as measured in CA) is not fully captured when constrained by 12 environmental variables in the CCA.

8.4 Summary

In summary, sites in the CCA plot are located along two major gradients; the first is a temperature gradient showing that samples tend to follow a seasonal pattern. The second is a nutrient gradient showing that samples are also affected by changes in nutrient levels, specifically TP, NO_3-N and DMRP.

PCA analysis and Pearson's product moment correlation coefficient showed that conductivity and alkalinity values had a strong positive correlation. PCA analysis also showed that samples taken from Loughs Inchiquin and Atedaun followed a similar trend and were located close to one another whereas samples taken from Lough Cullaun differed. This supports the classification of these lakes according to TP as in the OECD classification whereby Cullaun is an oligotrophic lake and Atedaun and Inchiquin are meso to eutrophic lakes. PCA analysis indicated that variables with long vectors such as alkalinity, conductivity, NO_3-N, rainfall, HWM and temperature have a larger influence on sample distribution than variables with short vectors such as TP, DMRP, chlorophyll-*a*, and pH. It is evident from both the PCA analysis and the examination of environmental data in Chapter 5 that environmental variables in each lake show a distinct seasonal trend.

CA was carried out on both cell count data and cell biovolume data. Although no major differences were found in dataset heterogeneity and ordination, eigenvalues in the CA ordination plot of biovolume samples and species resulted in a highly clustered biplot. An interesting result of this CA analysis is that it was evident which species made similar biovolume contributions, as these species were grouped close to one another. Further analysis of the biovolume dataset in constrained ordination produced non-significant

ordination axes. This result was not expected and maybe a result of data formatting and analysis problems with this dataset. This may have occurred at the measuring process of the biovolume samples. It was expected that cell biovolume values would be closely correlated with the sampled environmental variables. The majority of biovolume values are similar to those recorded in other studies (Hillebrand, 1999).

No problems were experienced with the unconstrained and constrained ordination of the algal cell count data. Both the species and sample CA plots had a triangular pattern. The position of samples in CA biplot suggested a seasonal pattern. The CA ordination showed that species with similar temperature preferences were also located close to each other. In CCA analysis two main groups of variables influenced the distribution of algal samples and species. The first group consisted of temperature, water level variation and Chlorophyll-*a* which represents a seasonal gradient. The second group consists of TP, $N0_3$-N and DMRP. This group of variables shows that the composition of phytoplankton samples is strongly influenced by changes in the nutrient status. The benefit of this analysis is that it combined physical, chemical and biological data and enabled a summary of the key patterns of variation in the data.

Chapter 9

Discussion

The research aims and objectives of this study were to (1) examine the variation in physical chemical characteristics of three interconnected lakes (Cullaun, Atedaun and Inchiquin) on a monthly basis over an annual cycle; (2) reassess the trophic classification for these lakes; (3) determine the taxonomic composition of algae in the open waters of these systems providing an in-depth examination of seasonal succession (4) provide a floral account of taxonomic composition and seasonal succession of periphyton in the littoral areas of these lakes (5) measure algal biovolume and (6) perform multivariate ordination analysis.

There is a long history of studies documenting seasonal changes in the composition of plankton communities in temperate lakes dating back to the 1930s e.g. Hutchinson (1944). However, there have only been a limited number of Irish studies to date that have focused intensively on periphyton and phytoplankton communities. This study provides a floral account and examines the algal communities through a number of current algal classifications and compares these results to other studies. In this chapter the results of this research are discussed according to the project aims and objectives under five key headings; physico-chemistry, trophic classification, seasonal succession in phytoplankton and periphyton communities, and the response of phytoplankton to changes in measured environmental variables. All findings are compared to results from other Irish and European studies.

9.1 Physico-chemistry

The physical and chemical patterns found in Loughs Atedaun, Cullaun and Inchiquin are described in detail in Chapter 5. Physically the lake waters are hard and highly alkaline and geographically they are located close to one another as shown in Figure 3.2. A number of key differences exist between the lakes in terms of their morphology and hydrology. Water flow, residence time, hydrological pattern and the pattern in time in which water arrives in the lake system all influence a lake's ecology. This determines the nutrient levels, plankton development and many other lake functions.

Water residence time in Lough Atedaun has been estimated to be less than one day with 450.6 flushing's occurring per year (Wemaëre, 2005). Physical manifestation of this high flushing rate is evident in the high variability in lake water level and low

secchi transparency relative to the two upstream lakes. In relation to seasonal secchi values; Inchiquin and Atedaun follow a similar pattern but the degree of change between months is far greater in Lough Atedaun. Atedaun was shown to be a shallow well mixed lake (mean depth 2m) with a high flushing rate with consequesnt ecological responses. Water level varied the least in Lough Cullaun and this lake had the highest secchi values showing that this was the most stable aquatic environment of the study sites. Lough Cullaun is a relatively deep lake (maximum depth 32m) with minimum differences in seasonal water levels and high secchi values. Inchiquin is a relatively deep lake (maximum depth 25m) with a low flushing rate. Oxygen depletion in the hypolimnion in the summer months indicative of summer stratification in Lough Inchiquin was first identified in the mid-1970s (Flanagan & Toner, 1975) and confirmed by Wemaëre in July 2000 and July 2001 (Wemaëre, 2005). It is assumed that stratification during the summer months does not take place in Lough Atedaun due to its high flushing rate and shallow depth. No data was collected or has previosuly been published regarding stratification in Cullaun, though it is certainly likey that stratification occurs.

Little monthly variation in pH, conductivity and alkalinity values were found between the three lakes. This was expected as all three lakes are situated within a karstic limestone area with alkalinity and pH providing good buffering capacity as determined by European Economic Classification (Premazzi & Cardoso, 2000). Examination of Chorophyll a patterns in each of the three lakes indicated that each of the lakes had different patterns. This was expected in Lough Cullaun which is an oligotrophic lake. However in Loughs Atedaun and Inchiquin patterns differed even though both lakes had similar temperature and TP values. The difference probably attributable to a combination of different hydrology's and more specifically to the high flushing rate in Atedaun. In relation to DMRP, which signifies the amount of phosphorous available for biological organisms each of the lakes followed a similar seasonal cycle, with higher amounts available in winter with low values during summer when biological activity is at a maximum. Within the sites Inchiquin had a greater availability of DMRP for biological consumption which undoubtedly contributed to the increased cell volume and bio volume values within this lake (see section 6.6.4).

Significant differences were found in the TP levels between each lake. Relatively high values occurred in Inchiquin (mean value 34 µg/l) and Atedaun (mean value 27 µg/l) which would indicate that these are both enriched systems compared to Lough Cullaun (mean value 9 µg/l). There was higher variation in monthly TP values in Lough Atedaun compared to Lough Inchiquin and this is an important factor when considering the algal community dynamics in each lake. Lough Cullaun exhibited little difference between winter and summer TP values indicating that this lake was relatively nutrient poor. There is a general seasonal pattern evident in Atedaun and Inchiquin which is most likely caused by these lakes having larger catchment areas with more agricultural and increased inputs of phosphorus in late spring (March/April) and early autumn (August/September). Seasonal differences also occur with high levels of rainfall during winter and increased loss of phosphorus to the sediment during calmer summer conditions when stratification and higher sinking rates can occur, this pattern has been described in a number of Irish studies (Clabby, 2001; Irvine *et al.*,2001; Free, 2002).

9.2 Assessment of Trophic Status

Historically assessment of trophic status is often based on single or a relatively small number of nutrient and chlorophyll measurements. The EU Water Framework Directive (European Union, 2000: WFD) states that the minimum sampling frequency for phytoplankton should be six monthly and for nutrient status quarterly (EPA, 2001; EPA, 2006). However the WFD also recommends that for phytoplankton and nutrient status more frequent sampling programme should take place (EPA 2006). Sampling frequency within this study surpassed the requirements of the WFD and as a result a more in-depth view was established. The trophic state of the study lakes has been classified in a number of previous studies using the OECD classification system (OECD 1982). Irvine *et al.* (2001) classified Atedaun as mesotrophic based on a single vertically integrated summer water sample. Wemaëre (2005) found that Atedaun was meso-eutrophic according to OECD TP classes. This study identified Atedaun as a highly mesotrophic lake, with a distinct seasonal pattern which showed that TP values could change significantly from month to month i.e. July 2006, 28 µg/l, August 2006, 67 µg/l, September 2006, 13 µg/l. This pattern shows that single monthly samples may not be effective in determining a lakes trophic state as values

can change rapidly within a short time frame. Therefore higher sampling frequencies are of greater benefit and care must be taken with results from one off samples which may provide a less comprehensive understanding of seasonal nutrient patterns.

Irvine *et al.,* (2001) classified Cullaun as mesotrophic based on a single vertically integrated summer water sample whilst Wemaëre (2005) found that Cullaun was oligo-mesotrophic. Reclassification of the trophic state in this study suggests that Lough Cullaun is at the higher end of the oligotrophic class. Cullaun's monthly TP shows the least amount of variability of the three lakes indicating that this is a relatively nutrient poor lake. The annual minimum TP value of 5 µg/l occurred in December, whilst the annual maximum TP value of 13 µg/l occurred in October with an annual mean value was 9 µg/l TP.

Flanagan & Toner (1975) reported that Inchiquin showed characteristics of eutrophy in the early 1970's. The EPA reported a mesotrophic classification for Inchiquin with a maximum TP of 15 µg/l between 1991-1994 (Bowman *et al*, 1996). In 2005 Wemaëre identified Inchiquin as being mesotrophic (Wemaëre, 2005). Reclassification of Inchiquin as a result of this study places Inchiquin just within the eutrophic category. Since 1970 Inchiquin has consistently shown signs of enrichment giving it a high trophic status with algal blooms also having occurred in previous years (Wemaëre, 2005). Inchiquin's water quality should be of serious concern to local authorities especially since it also supports significant numbers of brown trout.

Palaeolimnological investigations have succeeded in providing considerable detail on the recent history of lakes in Ireland and have been used to fulfill Water Framework objectives in establishing ecological reference conditions for lakes (Taylor *et al*., 2006 & 2007; Leira *et al*., 2006; Dalton *et al.,* 2009). Palaeolimnological reconstructions provide an important overview of past conditions in the study lakes (Taylor *et al*., 2007). Diatom inferred total phosporus reconstructions indicate that the trophic status of Inchiquin approached the eutrophic category during the 1990's. While Atedaun has showed a rapid increase in productivity towards the top of the core indicating a change in trophic status (from mesotrophic to eutrophic) (Taylor *et al.,* 2007). A comparison of sediment core top and bottom samples from Cullaun (the latter pre-dating *c*. 1850) indicated that a largely planktonic diatom flora has replaced the non-planktonic diatom reference assemblage at Cullaun (Taylor *et al*., 2007) thus

suggesting a deterioration in water quality over this time period. These palaeolimnological findings provide a longer term context and track the general pattern of deterioration in water quality in Loughs Atedaun, Cullaun and Inchiquin.

Reynolds *et al.,* (1998) comments that trophic state should not be thought of as a single dimension of a single factor but, rather, as a group of interrelated factors responding to productivity demands and the resources available. The monthly examination of physical and chemical factors in Atedaun, Cullaun and Inchiquin has shown that a large number of variables exist in a constant state of flux and are continuously at work shaping the trophic state of a lake. Importantly all environmental factors need to be considered as they push and pull on algal community dynamics within lakes. By examining and identifying the algal community within a water body it then allows us to understand the relationship between trophic state and phytoplankton assemblages.

9.3 Seasonal Succession in Phytoplankton

A detailed account of monthly phytoplankton changes in each study lake has been described in Chapter 6 along with an analysis of the plankton communities using various biological indices. In the following section key seasonal trends in each lake will be contrasted and then compared to national and international studies. The results of the winter samples taken in Lough Atedaun show that algal populations were at their lowest during winter. The Cryptophytes were most abundant in terms of cell counts while the diatoms tended to have the highest relative abundance and biomass. Allott (1990) noted that the small size of Cryptophyta species meant they would only be a small part of the algal biomass within a lake. However Irvine *et al.,* (2001) found that small single celled forms were an important contributor to phytoplankton biomass in his study of Lough Lene, a large lake in County Westmeath. The high abundance of diatoms during cooler months (January and February) in this study is consistent with findings from many studies of Irish lakes (Flanagan & Toner, 1975; Allott 1990; King & Champ, 2000; Irvine *et al.,* 2001) and international studies (Salmaso 2000; Huzar *et al,.* 2003; Nenad & Hafner 2005). Nenad & Hafner (2005) examined diatom seasonality in karstic lakes in Croatia and concluded that diatoms were better able to compete for nutrients at lower temperatures than other algae. Salmaso (2000) in a

study of northern Italian lakes found that samples from the coldest months produced large colonial diatoms, unicellular diatoms and small cryptophytes. The diatom *Asterionella* had the highest relative abundance in December and April in the Clare lakes. Elliott *et al*. (2006) attribute this to *Asterionella's* ability to adapt to low light situations and to colder temperatures. Reynolds *et al.,* (2002) classified *Asterionella* as having a preference for mixed eutrophic small to medium sized lakes such as Lough Atedaun. Diatoms were less abundant during summer when warmer temperatures allowed Chlorophyta and Cyanobacteria species to become more dominant. Cyanophyte species *Phormidium*, *Radiofilum* and *Micrococcus* were dominant species (in May, June and August respectively) in samples from Lough Atedaun. The identification of Cyanophytes during warmer months was expected and this is a documented occurrence in mesotrophic and eutrophic lakes (Allott, 1990; Salmaso, 2000; Irvine *et al.,* 2001).

Phytoplankton productivity measured by cell abundance was lower in Lough Atedaun than Lough Inchiquin even though both lakes had similar TP levels and similar water temperatures. Huszar *et al.* (2003) examined phytoplankton assemblages in a temperate lake (Lake Chodikee) in the North East of the USA. Atedaun and Chodikee are similar in that they are both mesoeutrophic lakes with high flushing rates. Huszar *et al*, (2003) found that the dominance of a species or a phytoplankton assemblage ends with major hydrographic change. This could be a rapid increase or decrease in water level as occurred in Lough Atedaun or a change in temperature. Flores & Barone (1998) in their study of two Italian reservoirs with different trophic states found irregular hydrological events override the seasonal cycle of phytoplankton biomass yielding irregular patterns of variability. Phytoplankton populations therefore in Lough Atedaun may be limited in growth by hydrographic changes as shown by the high variance in water levels. Phytoplankton populations in Atedaun were also strongly influenced by rapid changes in nutrient levels within the lake. TP levels in Atedaun jumped from 28 µg/l in July 2006 to 67 µg/l in August 2006. A corresponding change in cell volume values took place with August being the month with the highest cell volume values. Elliott *et al*. (2006) concluded that phytoplankton communities are sensitive to catchment derived changes in nutrient load (e.g. due to changes in agricultural practice, sewage treatment). This is an important water management issue especially since Lough Atedaun is part of the larger Fergus

catchment. Therefore changes in water temperature, nutrient load and water levels seemed to drive changes in the phytoplankton assemblages in Lough Atedaun.

Oligotrophic lakes in temperate zones tend to have low species diversity throughout the year (Watson *et al.,* 1997) and this was confirmed by findings in Lough Cullaun in this study. Winter samples from Cullaun had very low cell counts which increased only slightly during spring and summer. Most samples consisted of species from the Cryptophyta, Bacillariophyta and Chrysophyta groups a result similar to other studies on Cullaun (Allott, 1990; Free, 2002). *Cryptomonas* and *Rhodomonas* had a significant presence throughout the year, especially during colder months. Other studies on Cullaun (Allott, 1990; Free, 2002) and studies on nearby Lough Bunny (Pybus *et al.,* 1999 & 2001) an oligotrophic lake in similar bedrock and trophic state also found the Cryptophytes to be one of the more dominant groups. The Chrysophyte *Dinobryon* was abundant in this study just as it was in Allott (1990), Pybus *et al.*, (2001) and Free (2002). Reynolds *et al.,* (2002) classified *Dinobryon* as having a preference for usually small oligotrophic, base poor lakes with low nutrient levels. Cullaun is not a base poor lake however *Dinobryon* was still abundant possibly because of its ability to adapt to low nutrient levels. Diatoms were also abundant in samples from Lough Cullaun. The abundance of diatom species in oligotrophic lakes has been well documented (Lemly & Dimmick, 1982; Allott, 1990; Watson *et al.*, 1997; Irvine *et al.*, 2001; Pybus *et al.*,2001). Diatom species often predominate in oligotrophic conditions (Lemly & Dimmick, 1982) and can supply most of the phytoplankton biomass in lakes with low to moderate nutrient levels (Watson *et al.*, 1997). Diatom species made the largest contribution to algal biovolume in Lough Cullaun. TP levels in Lough Cullaun were low throughout the sampling period which suggests that changes in algal populations, species richness and abundance were more attributed to change in water temperatures rather than nutrient loading. This observation was also made by Nenad & Hafner (2005) in their study of diatoms in karstic oligotrophic lakes in Croatia.

Algal succession in Lough Inchiquin differed in some instances to the results from previous studies on this lake (Flanagan & Toner 1975; Allott 1990; Free 2002). Allott's study in 1990 (samples taken in 1981) documented that diatom species dominated in spring and Cryptophyte species dominated in the remaining months. In

Free's (2002) study (based on one sample taken in June 1996) the Cryptophytes *Rhodomonas* and *Cryptomonas* were the most abundant species with some Cyanophytes subdominant. Allott (1990) found an abundance of the Pyrrophyta *Ceratium* in late summer. Reynolds (2002) describes *Ceratium* as being found typically during summer in the epilimnia in eutrophic lakes. This algae was rarely found in the current study but it was listed as present in Flanagan and Toner's (1975) study of Lough Inchiquin. Significant populations of diatoms were found in Lough Inchiquin in this study, but on most occasions they were subdominant to the Cyanophytes and Chlorophytes. A spring bloom of the diatom *Asterionella* occurred in April where Allott (1990) found a bloom in March while Flanagan & Toner (1975) found *Asterionella* to be dominant in both the November and July samples. The differences between these studies reflect the different sampling regimes and also the variation in total phosphorus levels in Lough Inchiquin over the past twenty years. Mean TP levels were 22 µg/l in the late 1980s (Allott, 1990) while mean TP levels found in this study in 2006 were 34 ug/l. Inchiquin has also had a number of algal blooms during the summer months over the past 10 years, a phenomenon indicative of increasing nutrient levels within a lake. Many studies have correlated increased TP levels with the presence of Cyanophytes (Watson *et al.*, 1997; Rojo, 1998; Reynolds & Petersen 2000).

The chlorophytes that were most dominant in Lough Inchiquin, *Staurastrum* and *Scenedesmus,* are indicative of nutrient enriched lakes (Reynolds & Petersen, 2000). Reynolds *et al.,* (2002) has described *Scenedesmus* as having a preference for shallow enriched lakes. The Cyanophyte *Anabaena* found during summer months in this study is a species known to have adapted to environments which are phosphorus rich for part of the year (John *et al.,* 2002). The largest cell abundance value in this study occurred in Inchiquin at a time when Inchiquin also had its highest TP value. Some difficulties arise when using species as ecological indicators as emphasised by the fact that some species are tolerant of a wide range of trophic conditions e.g. *Cryptomonas.* This genus was found in abundance in this study, and was attributed to oligotrophic lakes by Allott (1990) while Reynolds & Petersen (2000) say it is indicative of mesotrophic and eutrophic conditions. Therefore although certain aspects of plankton dynamics are broadly predictable i.e. spring blooms in temperate lakes. Other patterns

are quite complex and unpredictable as a result of the ability of certain species to tolerate a wide range of conditions.

Watson *et al,*. (1997) examined 91 mesotrophic (TP range 10-30 µg/l) northern temperate US lakes. She found all taxonomic groups evenly represented at intermediate TP levels but exhibiting very different structural patterns with increasing phosphorous levels. In the Clare lakes increases in TP values did result in changes in how taxonomic groups were represented. In Lough Inchiquin the Shannon diversity index and evenness values showed a distinct trend over the annual cycle with significant change occurring as TP values increased. Inchiquin had the highest mean TP value in this study and coincidentally a different biovolume pattern took place in Lough Inchiquin compared to the other two lakes. There was a noticeable presence in Cyanophyte biovolume compared to both other lakes; this resulted in a reduction in the biovolume of Chlorophyte, Bacillariophyte and Cryptophyte species. In both this study and Watsons (Watson *et al,*. 1997) it was found that in mesotrophic lakes most algal groups are represented over the growing season especially Bacillariophycae, Chlorophyta, Cryptophyta, Dinophyta as well as Cyanobacteria and Chrysophyceae. Watson also states that in oligotrophic systems diatoms supply most of the phytoplankton biomass in lakes with low to moderate nutrient levels (10 -30 µg/l TP) but they are subdominant to blue greens in more eutrophic lakes (30 µg/l TP). This pattern was replicated in the Clare lakes.

It is possible to conclude that Lough Atedaun's phytoplankton assemblage was typical of a mesotrophic lake though monthly changes in assemblages were strongly influenced by changes in temperature, nutrient loading and water level. Lough Cullaun’s phytoplankton assemblage was typical of an oligotrophic lake and corresponded with findings from national and international studies. When Lough Atedaun and Inchiquin are compared the effect of water residence time and changes in water level can be seen to directly affect not just cell abundance values, but species composition and biovolumes. Lough Inchiquin’s assemblage was similar to those found in other studies of meso to eutrophic lakes. The predominance of green and blue green algae especially during summer months is of concern and could possibly be a source of future algal blooms and reductions in water quality.

9.4 Variation in Periphyton

There have been relatively few studies of periphyton patterns in lakes and limited data exists detailing monthly changes in periphyton species composition over an annual cycle. The historical perception has been that planktonic algae are the dominant primary producers of lentic ecosystems although this has changed more recently (Stevenson *et al*., 1996; Vadeboncour & Steinman, 2002; Vadeboncour *et al*., 2008). The record of published research in leading international aquatic journals (i.e. Limnology & Hydrobiologia) reflects this plankton research bias, with phytoplankton based research papers outnumbering periphyton based research papers by about 20 to 1 (Stevenson *et al*.,1996). Recent periphyton studies in Ireland have included Barbiero (2000) who examined the effect of natural and artificial substrates on epilithic diatom communities, DeNicola *et al.*,(2003) who examined the ability of epilithic algae to assess trophic status and DeNicola *et al*., (2004) who looked at the production and respiration of epilithic algal communities in Irish lakes of different trophic status. These papers represent the only recent studies on lake periphyton in Ireland.

The qualitative examination of periphyton samples from Atedaun, Cullaun and Inchiquin was a second study objective with the focus of providing a seasonal floral account of periphyton change within the study lakes. Only a semi quantative assessment was made due to the highly variable nature of the rock substrates and the variable sample biomass. Periphyton samples comprised species from the Bacillariophyta, Cyanophyta and Chlorophyta groups, similar to many other studies (Stevenson *et al.,* 1996; DeNicola *et al*., 2003 & 2004). No Rhodophyceae (red algae) were found in samples in this study, although these algae are known to be a part of many periphyton samples (Stevenson *et al.,* 1996). The samples in this study were taken from the upper littoral zone, which is usually dominated by algae capable of attaching tightly to substratum. Seasonal species change occurred as expected and documented for temperate lakes which experience strong seasonal temperature changes (Stevenson *et al.,* 1996; Vadeboncoeur & Steinman, 2002). Hard water lakes have also been known to have an abundance of filamentous genera including the chlorophytes *Cladophora*, *Ulothrix* and *Oedigonium* (Stevenson & Stoermer, 1981), however, this occurrence was not obvious in the Clare lakes. Stevenson *et al*., (1996) lists the diatoms *Cymbella, Rhoicosphenia, Amphora*, *Navicula* and *Achnanthidium* as

species often found in the eulittoral (littoral areas 0 – 1 meters in depth) zone of hard water lakes. The Cyanophyte *Lyngbya* is also a typical of species found in the eulittoral zone of hard water lakes; this species was found on several occasions in samples from the Clare lakes.

The diatoms were the most abundant group in Loughs Ataedun and Cullaun, probaly because they are well adapted to the stone substrata that were examined. In Lough Atedaun diatoms dominated on most occasions followed by the Cyanophytes and then the Chlorophytes. A similar pattern occurred in Lough Cullaun. In Inchiquin there was little difference between the proportions of each of the three algal groups. The Chlorophytes and the Cyanophytes represented a larger proportion of species numbers compared to the other two lakes. This is probably attributed to the higher nutrient levels in Inchiquin. Cattaneo (1987) found that diatoms were dominant in most periphyton assemblages but tend to be replaced by green algae in more enriched sites a pattern also seen in this study. DeNicola *et al*. (2003) found that diatoms and desmids were generally more abundant in oligotrophic and mesotrophic lakes whilst eutrophic lakes were characterised by cyanobacteria taxa. The association between water column nutrients and algal biomass is generally stronger for phytoplankton than for periphyton (Cattaneo, 1987). However when Irish lakes are considered De Nicola *et al*. (2003) state that a monitoring program based on periphyton may be more suitable for many lakes. This is because of their hydrology (shallow with short retention times) combined with extensive rocky littoral areas which are characteristic of many Irish lakes. This can cause high rates of primary production and therefore is likely to be a large contributor to whole lake production (De Nicola *et al*. 2003). Littoral diatoms have been successfully used in many studies as indicators of eutrophication, with TP often being identified as a major environmental gradient controlling periphyton species composition (Cattaneo, 1987; Kitner & Poulíčková, 2003; DeNicola *et al.,* 2003 & 2004; King *et al.,* 2000). In many studies additional variance in periphytic algal composition was related to pH/alkalinity which is attributed to geology and land use (DeNicola *et al*., 2003 & 2004). However in this study pH/alkakinity was similar for each of the three lakes therefore it is assumed that the main drivers of periphyton change are changes in temperature and nutrient level. Cattaneo (1987) in his study of 10 lakes in Eastern townships in Quebec found that cell volume was the best index of periphyton biomass and was positively correlated

with TP. However he also found that factors not measured in this study such as exposure to waves positively influenced periphyton cell volume.

9.5 Phytoplankton responses to changes in environment variables

Ordination analysis was used in order to summarise the relationship between phytoplankton and environmental variables. Principal Component Analysis (PCA) of the environmental variables in the three lakes identified a primary axis correlated with alkalinity, conductivity and temperature and a second axis correlated with rainfall. PCA highlighted that samples taken during warmer months were strongly influenced by temperature and nutrients while rainfall affected the winter samples. A clear seasonal pattern was evident in the combined samples. CA followed by Canonical Correspondence Analysis (CCA) identified two main environmental gradients influencing phytoplankton distribution in the three study lakes over the annual period 2005 - 2006, a primary seasonal gradient associated with temperature, water level variation and Chlorophyll-*a* and a second nutrient gradient associated with TP, $N0_3$-N and DMRP. These results were compared with a range of published results from similar aquatic conditions (Flores & Barone 1998; King *et al.*, 2000; Elliott *et al.*, 2004; Elliott *et al*., 2006). King *et al.*, (2000) in a UK study found that two major environmental gradients controlled the species composition of assemblages. The first was TP and the second was ionic concentration illustrated by Ca, DIC and conductivity. Flores & Barone (1998) identified water volume, conductivity, mixing depth and temperature to be the four most significant factors explaining the variance in phytoplankton assemblages in their samples through CCA. Elliott *et al*. (2006) looked at the sensitivity of phytoplankton to changes in temperature and nutrient load in a temperate lake in the north of England. They found that increases in nutrient load had a greater effect on species diversity than increases in temperature. Elliott *et al*., (2004) using the PROTECH model (Phytoplankton RespOnses To Environmental CHange) in simulated tests in lakes and reservoirs highlighted that the main ecological change in the lake environment was a response to an increase in water temperature. Results from this study supports Elliott's *et al.,* (2004) suggestion that control of the nutrient supply to a lake reduces the development of undesirable species (i.e. Cyanobacteria blooms).

The relationship between temperature and algal assemblage composition has been well documented (Hutchinson 1957 & 1961; Reynolds 1984; Wetzel 2001). Inclusion of water temperature measurements in the current study confirmed the seasonal nature of plankton growth and the temperature preference of a number of species. Two other physical variables which were significant in CCA analysis were rainfall and water level variation. Stevenson *et al.,* (1996) confirmed a link between a change in rainfall and water levels and plankton growth rate. Increased rainfall results in increased run off which when mixed with nutrients from agriculture and farming activities will result in increased TP levels entering a lake which will then influence algal dynamics. Increased rainfall also affects water level variation, mixing rate and stratification, all factors which directly affect plankton growth (Salmaso, 2000; Huszar *et al.*, 2003). In addition during periods of severe flushing nutrients could be washed out of the lake, reducing TP levels, whereas during dry periods and longer residence times nutrient levels potentially increase (Allott 1990; Flores & Barone 1998). These mechanisms can be used to explain the differences in algal dynamics between Loughs Atedaun and Inchiquin. While Atedaun and Inchiquin on occasion had similar TP and temperature values their algal cell count and biovolume values differed greatly due to their different hydrological regimes.

The other important ordination gradient explaining variation in the plankton assemblages was a nutrient gradient (TP, $N0_3$-N and DMRP). The relationship between TP and plankton dynamics has been well established with TP often found to be one of the most important variables affecting phytoplankton and periphyton. Many studies (Cattaneo, 1987; Watson *et al.,* 1997; King *et al.,* 2000; DeNicola *et al.,* 2004; Liboriussen & Jeppesen, 2006; Leira *et al*., 2009) have explored species response to TP using advanced statistical analysis techinques such as regression analysis, weighted averaging and the transfer function approach. These techniques measure the strength of the relationship between a variable and its species optima and tolerance range.

Reynolds *et al.,* (1998) states that the Euglenophyte *Eudorina* is known to increase in abundance during warm periods and is closely associated with high TP levels along with *Trachlemonas* and *Mallomonas* an occurrence also seen in the Clare lakes. Addittionally *Chlamydomonas*, *Chlorella*, *Chroococcus*, *Closteriopsis* and

*Oscillatori*a which are all located near to the TP vector line and therefore would be significantly affected by changes in this variable. Reynolds *et al.,* (1998) has shown that each of these species to have preferences for certain locations along the trophic gradient, however a specie such as *Chlorella* can exist almost entirely across the full trophic spectrum.

When the CA (unconstrained) and CCA (constrained) ordinations are compared a number of differences are apparent. The % variance in the unconstrained phytoplankton data is only partially captured when constrained by 12 environmental variables in the CCA. This implies that other variables not measured in this study are having an effect on algal dynamics e.g. grazing. What is evident from this study and supported by findings in other studies is that temperature and nutrient load are probably the two most important drivers of change in algal communities (Salmaso, 2000; Huszar *et al.*, 2003; Elliott *et al.,* 2006). Other driver's e.g. grazing, mortality, mixing and stratification which influence algal dynamics were not measured in the Clare lakes and is a limitation of the current study.

The CCA ordination of cell biovolume data constrained by the environmental variables was not significant. This may have been an artefact of the data where the response data is dominated by a few large celled species and requires further interrogation. Despite this, biovolume proved a very useful algal indicator along with cell count data. It broadened the possibilities for examination of the seasonal pattern of algal succession in each lake. It also highlighted that while some species are prevalent in terms of cell abundance they may not be prevalent in terms of biovolume. This confirms the findings of recent studies (Hillebrand *et al.,* 1999; Wetzel, 2001; Kalff, 2001; DeNicola *et al.,* 2003) where biovolume provides a useful additional measure of algal assemblages.

9.5 Recommendations

There is much scope for limnological based investigations in Ireland's freshwater lakes. However serious challenges exist for policy makers and water managers particularly in terms of the implementation of the Water Framework Directive (2000). The establishment of 'clean' reference conditions as required by the WFD is difficult when no historical data exists on lakes (Domingues *et al.,* 2008). Few

palaeolimnological studies have been carried in Ireland prior to the development of the WFD relative to other countries in Europe (Dalton *et al.*, 2009). Since 2000 a number of EPA funded projects have sought to address this problem e.g. ILLUMINATE and IN-SIGHT establishing reference conditions for a number of Irish lakes. This information can be used as a basis for reconstructing past conditions and biological assemblages (of algae) prior to human impact (Dalton *et al.*, 2009).

There is a limited range of data on seasonal changes in the periphyton and plankton communities in different lake types. While there are a number of algal data sets in various project reports, publications and theses (undergraduate, masters and doctoral) most of these sources are not well publicised and are not easily accessible. Most studies are not concerned with developing basic floral accounts due to the time and expense required, though there is a need for such baseline information. More detailed sampling projects are required on a representative range of lakes in Ireland as a baseline to enable evaluation of natural variation and anthropogenic change for different lake types. Many Irish projects to date have been constrained by a small spatial sampling scale and limited sampling regime. There is a need at this stage to collate current algae records and construct a regional database which could aid in development of a regional classification systems or lake type species list.

The high rate of change within algal assemblages has lead to criticisms of the WFD for not being comprehensive enough in terms of its sampling frequencies (Padisak *et al.*, 2006). In relation to this Padisak *et al.*, (2006) state that there are four distinguishable stages in any year (winter time, spring diatom phase, clear water phase and late summer phase) and it is essential that these phases are monitored in any algal study. Lake classification is influenced by the environmental variables measured, the sampling approach and the frequency of sampling. The findings from this study confirm that increased enrichment has taken place within Loughs Atedaun and Inchiquin but to a lesser degree in Cullaun. It was also identified that discrete classification systems can be problematic as many lakes fall between two classes and large physical and chemical differences can exist within a single class.

Except for a few recent studies relatively little is known about the periphyton communities in Irish lakes. There is a lot of room for research regarding interactions between periphyton and phytoplankton and how these results might relate to results

from current paleolimnolgical studies. A better understanding of periphyton and phytoplankton responses and interactions of environmental factors at different spatial scales in Irish lakes is needed (DeNicola *et al.,* 2003).

More studies are needed examining the use of biovolume as an algal indicator especially in comparison to the more commonly used indicators of cell count and Chlorophyll-*a* values. Clarification in relation to the trophic status of lakes is required and how trophic state relates to algal community composition in terms of both phytoplankton and periphyton. It was beyond the scope of this study to examine the many internal factors affecting individual taxonomic groups (e, g nutrient uptake, competition, division rates, sinking and grazing losses) but these are key areas for future studies on Irish lakes.

Finally the study of phytoplankton and specifically their relation to chemical variables is a complex area. Even though well-known general trends exist between phytoplankton and water chemistry variables, it is extremely difficult to separate which particular variable has the most significant relationship with a particular phytoplankton (Moss, 2007). While certain algae have been linked to certain conditions through functional classifications (Reynolds *et al.,* 2002) the ability of many algae to adapt to a wide range of conditions means that time and caution are required when developing assumptions on species tolerance and preference ranges.

References

Allott, N.A. 1986. Temperature, oxygen and heat budgets of six small western Irish lakes. Freshwater Biology. 16, 145 – 154.

Allott, N.A. 1990. Limnology of six western Irish lakes in Co. Clare with reference to other temperate oceanic lakes. Unpublished Ph.D. Trinity College Dublin.

APHA (American Public Health Association). 1998. Standard methods for the examination of water and wastewater. (20th Edition). American Public Health Association. Washington DC.

Armstrong, F.A.J., Sterns, C.R. and Strickland, J.D.H.. 1967 The measurement of upwelling and subsequent biological processes by means of the Technicon AutoAnalyser and associated equipment. *Deep Sea Research,* 14: 381:389.

Barbiero R.P. 2000. A multi-lake comparison of epilithic diatom communities on natural and artifical substrates. Hydrobiologia 438, 157-2000.

Bourrelly, P. 1966. Les Algues d'eau douce, Vol. 1, Les algues vertes. N. Boubée & Cie, Paris.

Bourrelly, P. 1968. Les Algues d'eau douce, Vol. 2, Les algues jaunes et brunes. N. Boubée & Cie, Paris.

Bourrelly, P. 1981. Les Algues d'eau douce. Initation á la Sustématique. Tome *II.* Les Algues at Brunes. Chrysophycées, Phéophycées, Xanthrophycées et Diatomées. Boubée & Cie, Paris.

Bowman, J.J., Clabby, K.J., Lucey, J., McGarrigle, M.L. & Toner, P.F. 1996. Water Quyality in Ireland: 1991 – 1994. Wexford: Environmental protection Agency.

Brönmark, C. & Hansson, L.A. 2005. The Biology of lakes and ponds. Oxford University Press. Oxford.

Campbell, M.K & Farrell, S.O. 2003. Biochemistry. Thompson, Brooks, Cole. U.S.A.

Carpenter, S.R. & J.F. Kitchell (Eds). 1998 p 18. The trophic cascade in lakes. Cambridge University Press, Cambridge, 383PP.

Carpenter, S.R., Cottingham, K.L. & Schindler, D.E. 1992. Biotic feedbacks in lake phosphorus cycles. Tree 7: 332-335.

Cattaneo, A. 1987. Periphyton in lakes of different trophy. Canadian Journal of Fisheries & Aquatic Science.Vol 44: 296 – 303

Clabby, K.J., Lucey, J. & McGarrigle, M.L. 2001. Interim report on the biological survey of river quality, Results of the 2001 investigations. Environmental Protection Agency.

Clesceri, L.S., Greenberg, A.E. & Trussell, R.R. 1989. Standard Methods for the Examination of Water and Wastewater. American Publication Health Association, Washington D.C.

Cox, E.J. 1996. Identification of Freshwater Diatoms from Live Material. Chapman & Hall. London.

Coxon, C. 1995. Groundwater vulnerability and protection issues in the lower Fergus catchment. Co. Clare. In Hydrological Aspects of Groundwater Protection in Karstic Areas (COST Action 65 Final Report) European Commission D-G XII, Luxembourg. 162-169.

Coxon, C. & Drew. D.P. 2000. Interdependence of groundwater and surface water in lowland karst areas of western Ireland: management issues from water and contaminant transfers. Geological Society of London 182 81-88.

Dalton C., Taylor D. & Jennings E. 2009. The role of palaeolimnology in implementing the Water Framework Directive in Ireland. Biology and Environemnt: Proceedings of the Royal Irish Academy 109B: 161-174.

Daly, K. & Casey, A. 2000. Eutrophication from agricultural sources, Environmental soil phosphorus test. (2000-LS-2.1.6-M2) Final Report. Environmental Protection Agency. Wexford.

Davison, W. 1990. A practical guide to pH measurement in freshwaters. *Trends in Analytical Chemistry,* 9, 80-83.

Drew D.P. 1988a. The Hydrology of the Upper Fergus River catchment, County Clare. Proceedings of the University of Bristol Speleological Society, 18 (2), pp: 265-277.

Drew D.P.1988b. The Hydrology of the Burren. Irish Geography, 23 (2), pp: 69-89.

Dixit S.S., Smol, J.P & Kingston J.C. 1992. Diatoms: powerful indicators of environmental change. Environment Science Technology, 26, 23-32.

De Angelis, D.L., 1992. Dynamics of nutrient cycling and food webs. Chapman & Hall, 270pp

DeNicola, D.M., de Eyto, E., Wemaëre, A & Irvine, K. 2003. Production and respiration of epilithic algal communities in Irish lakes of different trophic status. Arch. Hydrobiol. 157: 67-87.

DeNicola, D.M., de Eyto, E., Wemaëre, A & Irvine, K. 2004. Using epilithic algal communities to assess trophic status in Irish lakes. J.Phycol. 40, 481-495.

Domingues, B., Barbosa, A. & Galvao, H. 2008. Constraints on the use of phytoplankton as a biological quality element within the Water Framework Directive in Portuguese waters. Marine Pollution Buletin 56 1389 – 1395.

Elliott, J.A. & Thackeray, S.J. 2004. The simulation of phytoplankton in shallow and deep lakes using PROTECH. Ecological Modelling178: 357 – 369

Elliott, J.A., Jones, I.D., & Thackeray, S.J. 2006. Testing the sensitivity of phytoplankton communities to changes in water temperature and nutrient load, in a temperate lake. Hydrobiologia 559:401-411

EPA. 2001a. Parameters of water quality. Interpretation and standards. Environmental protection agency, Wexford, Ireland.

EPA. 2001b. Phosphorus regulations national implementation report. Environmental protection agency, Wexford, Ireland.

EPA. 2006. Water Framework Directive Monitoring programme. Preparing to meet the requirements of the Water Framework Directive. Environmental protection Agency.Wexford.

Eisenreich, S.J., Bannerman, R.T. & Armstrong, D.E..1975. A simplified phosphorus analysis technique. *Environmental Letters,* 9, 43-53.

European Union. 2000. Directive 2000/60/EC of the European Parliament and the Council of 23 October 2000 –Establishing a framework for community action in the field of water policy. Official Journal of European Communities, 1 – 72.

Finch T. 1971. Soils of County Clare. An Foras Talúntais, Dublin

Fitts, R.C. 2002. Groundwater science. Elseiver Press. California.

Flangan, P.J. & Toner, P.F. 1975. A Preliminary Survey of Irish Lakes. An Foras Forbatha. Dublin.

Flores, L.N. & Barone, R. 1998. Phytoplankton dynamics in two reservoirs with different trophic state (Lake Rosamarina amd Lake Arancino, Sicily, Italy). Hydrobiologia 369/370: 163 - 178

Foged, N. 1977. Freshwater Diatoms in Ireland. Biblotheca Phycologica, 34, 221.

Free, G. 2002. The relationship between catchment characteristics and lake chemistry in the Republic of Ireland. Unpublished Ph.D thesis, Trinity College Dublin. Dublin.

Graham & Wilcox. 2000. Algae. Prentice Hall. New York.

Hansson, L.A. 1992. Factors regulating periphytic algal biomass. Limnol. Oceanogr. 37 (2), 322 -328.

Hellawell, J.M. 1978. Biological surveillance of rivers. Water Research Unit, Stevenage.

Hillebrand, H., Durslen. C.D. & Kirrschtel, D. 1999. Biovolume calculation for the pelagic and benthic microalgae. Journal of Phycology 35, 403 – 424.

Huszar, V., Kruk, C. & Caraco, N. 2003. Steady state assemblages of phytoplankton in four temperate lakes (N.E U.S.A). Hydrobiologia 502: 97 – 109

Hutchinson, G.E. 1944. Limnological studies in Conneticut. VII. A critical relationship examination of the supposed relationship between phytoplankton periodicity and chemical changes in lake waters. Ecology, 25: 3-26.

Hutchinson, G.E. 1957. A Treatise on Limnology, Volume 1. John Wiley & Sons. New York.

Hutchinson, G. E. 1961. The paradox of the plankton. American Naturalist 95: 137-145.

Irvine, K., Allott, N., De Eyto, E., Free, G., White, J., Caroni, R., Kennelly, C., Keaney, J., Lennon, C., Kemp, A., Barry, E., Day, S., Mills, P., O' Riain, G., Quirke, B., Twomey, H., Sweeney, P. (2001). The Ecological Assessment of Irish Lakes: the development of a new methodology suited to the needs of the EU Directive for surface waters. Environmental Protection Agency, Wexford.

Jeffries, M. & Mills, D. 1990. Freshwater Ecology. John Wiley & sons. London.

Jennings, E., Mills, P, Jordan. P., Jensen , J.P., Sondergaard, M., Barr, A., Glasgow, G. & Irvine, K. 2004. Eutrophication from agricultural sources, Seasonal patterns & effects of phosphorus. (2000-LS-2.1.7-M2). Environmental Protection Agency. Wexford.

John, D., Whitton, B.A & Brook A.J. 2002. The freshwater algal flora of the British Isles. Cambridge University Press. Cambridge.

Juggins, S. 2003. C2 User guide - Software for ecological and paleocological data analysis and visualisation. University of Newcastle. Newcastle upon Tyne, UK.

Kalff, J. 2001.Limnology, Inland water systems. Prentice Hall. New Jersey.

King, J.J & Champ, W.S.T. 2000. Baseline water quality investigations on Lough Carra, Westeren Ireland, with reference to water chemistry, phytoplankton and aquatic plants. Biology and Environment: Proceedings of the Royal Irish Academy, 100 (B), 13 – 25.

King, L., Barker, P. & Jones R.I. 2000. Epilithic algal communities and their relationship to environmental variables in lakes of the English lake district. Freshwater Biology 45, 425-442.

Kirschtel, D. 1993. BIOVOL manual. Department of Botany, University of Vermont, USA.

Kitner, M. & Poulíčková, A. 2003. Littoral diatoms as indicators for the eutrophication of shallow lakes. Hydrobiologia 506-509: 519-524, 2003.

Lehman, J.T & Sandgren, G.D. 1985. Species specific rates of growth and grazing loss among freshwater algae. Limnol Oceanography. 30: 34-46.

Leira, M., Jordan, P., Taylor, D., Dalton, C., Bennion, H., Rose, N., Irvine, K., 2006. Assessing the ecological status of candidate reference lakes in Ireland using palaeolimnology, Journal of Applied Ecology, 43, 2006, 816 - 827

Leira, M., Dalton,C., Chen, G., Irvine, K. and Taylor, D., 2009. Patterns in freshwater diatom taxonomic distinctness along an eutrophication gradient , Freshwater Biology, 54, 2009, 1 - 14

Lepš, J. & Šmilauer, P. 2003. Multivariate Analysis of Ecological Data using CANOCO. Cambridge University Press. Cambridge.

Liboriussen, L. & Jeppesen, E. 2006. Structure, biomass, production and depth distribution of periphyton on artificial substratum in shallow lakes with contrasting nutrient concentrations. Freshwater Biology 51, 95 -109

Lucey, J., Bowman, J.J., Clabby, K.J., Cunningham, P., Lehane, M., MacCarthaigh, M., McGarrigle, M.L and Toner P.F. 1999 Water quality in Ireland 1995-1997. Environmental Protection Agency, Ireland.

Lemly A.D & Dimmick. J.F. 1982. Phytopklankton communities in the littoral zone of lakes; Observations on structure and dynamics in oligotrophic and eutrophic systems. Oecologia 54: 359 – 369.

McGarrigle, M.L., Bowman, J.J., Clabby, K.J., Cunningham, P., MacCarthaigh, M., Keegan, M., Cantrell, B., Lehane, M., Clenaghan, C. & Toner, P.F. 2002. Water Quality in Ireland: 1998 -2000. Environmental Protection Agency. Wexford.

McNally, T. 2009. Overview of the EU Water Framework Directive and its implementation in Ireland. Biology and the Environment; Proceedings of the Royal Irish Academy 109B; 131-138.

Met Eireann 2004. Monthly annual rainfall data for County Clare (Claremorris meteorlogical station).www.meteireann.ie

Moss, B. 1998. Ecology of fresh waters man and medium, past to future (third ed). Oxford: Blackwell science.

Moss, B. 2007. Shallow lakes the water framework directive and life. What should it all be about? Hydrobiologia 548; 381-394

Nalewajiko, C & Dean. R.S, 1978. Phosphorus kinetics-algal; growth requirements in batch cultures. Mitt. Int. Ver. Theor. Angew. Limnol 21:184 – 192.

Nenad, J. & Hafner, D. 2005. Taxonomic composition and seasonality of diatoms in three Dinaric karstic lakes in Croatia. Limnologica 35: 304 – 319

Ní Chatháin, B. 2002. Investigation of the ecology of benthic algae in the river Deel, south west Ireland. Unpublished PhD. University of Limerick.

Organisation for economic Cooperation and Development (OECD). 1982. Eutrophication of waters. Monitoring assessment and control final report. OECD Cooperative programme on monitoring of Inland waters (Eutrophication Control) OECD Paris, 156pp.

Padisak, J., Borics, G., Grigorszky, I. & Soroczki-Pinter, E. 2006. Use of phytoplankton assemblages for monitoring ecological status of lakes within the Water Framework Directive; the assemblage index. Hydriobiologia 553;1 – 14.

Premazzi, G. & Cardoso A. C. 2000. Hydrological and limnological aspects of lake monitoring. Edited by Pertti, H., Ziglio, G. & Van Der Beken, A. John Wiley & Sons Ltd. London.

Pybus, M.J. & Pybus, C. 2001. Phytoplankton and Charophytes of Lough Bunny Co. Clare. Biology and Environment. Royal Irish Academy, Vol 103 (B), No. 3, 177 – 185.

Pybus, C., Pybus, M.J. & Ragneborn-Tough, L. 1999. A Hydrographic study of Lough Bunny, Co. Clare. Biology and environment. Royal Irish Academy, Vol 99B, No. 3, 191 -196.

Rawson, D.S. 1956. Algae Indicators of trophic lake types. Limnology and Oceanography, Vol. 1, No. 1, pp. 18-25.

Reynolds, C.S. 1980.Phytoplankton assemblages and their periodicity in stratifying lake systems. Holarctic Eciol. 3; 141- 159.

Reynolds, C.S. 1984. The ecology of freshwater algae. Cambridge University Press. New York.

Reynolds, C.S. & Peterson, A.C. 2000. The distribution of planktonic Cyanobacteria in Irish lakes in relation to their trophic status. Hydrobiologia 424: 91 -99.

Reynolds, C.S., Cobelas, Alvarez M., Castillo, Sanchez, P. & Kristiansen, J. 1998. What factors influence the species composition of phytoplankton in lakes of different trophic status? Hydrobiologia 369/370: 11-26.

Reynolds, J.D. 1998. Irelands Freshwaters. International Association of Theoretical and Applied Limnology XXVII Congress, Dublin, Ireland. Trinity College, Dublin.

Reynolds, C.S., Huszar, V., Kruk, C., Naselli-Flores, L. & Melo, S. 2002. Towards a functional classification of the freshwater phytoplankton.Journal of Plankton Research.**24** 417 – 428

Rojo, C. 1998. Differential attributes of phytoplankton across the trophic gradient: a conceptual landscape with gaps. Hydrobiologia 369/370; 1-9, 1998.

Round, F.E., Crawford, R.M. & Mann, D.G. 1990. The Diatoms, Biology and Morphology of the Genera. Cambridge University press. Cambridge.

Salmaso N. 2000. Factors affecting the seasonality and distribution of cyanobacteria and chlorophytes; a case study from the large alkes south of the alps, with special reference to lake Garda. Hydrobiologia 438: 43 – 63

Scheffer, M. 2004. Ecology of shallow lakes. Klumwer Academic Publishers. Dordrecht.

Shaw, P.J. 2003. Multivariate Statistics for the Environmental Sciences. Hodder Arnold. London

Standing Committee of Analysts 1983. The determination of chlorophyll *a* in aquatic environments 1980. HMSO.

Stevenson, R.J. & & Stoermer, E.F. 1981. Quantitative differences between benthic algal communities along a depth gradient in Lake Michigan. J.Phycol. 17, 29 – 36.

Stevenson, R.J., Bothwell M. L. & Lowe R.L. (Eds) 1996. Algal Ecology- Freshwater benthic ecosystems. Stevenson. R.J., Bothwell. M.L. & Rex. L.L. 1996. Algal ecology freshwater benthic ecosystems. Academic Press. San Diego.

Sun. J & Liu, D. 2003. Geometric models for calculating cell biovolume and surface area for phytoplankton. Journal of Plankton Research. Vol. 25, No. 11, 1331 – 1346.

Taylor, D., Dalton, C., Leira, M., Jordan, P., Chen, G., León-Vintró, L., Irivne, K., Bennion, H., Nolan, T. 2006. Recent histories of six productive lakes in the Irish Ecoregion based on multiproxy palaeolimnological evidence, Hydrobiologia, 571, 2006, 237 – 259

Taylor, D., Dalton, C. Leira, M., Jordan, P., Irvine, K., Bennion, H., Magee, E. & León-Vintro, L. 2007. *Identification of refereNce-Status for Irish lake typoloGies using palaeolimnological metHods and Techniques (IN-SIGHT)*, Wexford, Ireland, EPA Ireland Final Report.

Ter Braak, C.J.F. 1986. Canonical Correspondence Analysis: A new Eigen vector technique for Multivariate Direct gradient Analysis. Ecology, Vol. 67, No. 5, pp.1167 – 1179.

Ter Braak, C.J.F. 1987. Ordination. In R.H.G. Jongman, C.J.F. ter Braak & O.F.R. van Tongeren (EDS.) Data analysis in Community and Landscape Ecology (pp. 78 - 90). Wageningen. Pudoc.

Ter Braak, C.J.F., & Smilauer, P. 2002. CANOCO reference manual and CanoDraw for Windows Users Guide: Software for Canonical Community ordination (version 4.5). Microcomputer Power. Ithaca, NY, USA.

Tillman, D. 1982. Resource competition and community structure. Princeton Univ. Press, Princeton 296pp.

Trainor. F.R. 1978. Phycology. John Wiley & Sons. New York.

Toner, P., Bowman, J., Clabby, K., Lucey, J., McGarrigle, M., Concannon, C., Clenaghan, C., Cunningham, P., Delaney, J., O'Boyle, S., MacCáthaigh, M., Craig, M. & Quinn. R. 2005. Water Quality in Ireland 2001-2003. Environmental Protection Agency, Wexford, Ireland.

Vadeboncour, Y. & Steinman, A. 2002. Periphyton function in Lake Ecosystems. TheScientificWorldJOURNAL (2002) 2, 1449–1468.

Vadeboncour, Y., Peterson, G., Vander Zanden, J.M. & Kalff, J. 2008. Benthic algala production across lake size gradients: intercations amongst morphometry, nutrients and light.Ecology 89 (9), 2542 – 2552.

Waemëre, A. 2005. Influence of catchment characteristics on the relationship between land use and lake water quality in County Clare. Volume 1. Unpublished PhD, Trinity College Dublin, Dublin.

Washington, H.G. 1982. Diversity, Biotic and Similarity Indices, A review with special relevance to aquatic systems. Water Research. Vol. 18, No. 6, pp. 653 – 694. Pergamon Press Ltd.

Watson. S.B., McCauley, E. & Downing J.A. 1997. Patterns in phytoplankton taxonomic composition across temperate lakes of differing nutrient status. Limnol.Oceanogr. 42(3), 487-495.

Wetzel R. G. 2001. Limnology Lake and River Ecosystems 3rd edition. Academic Press. London.

Wetzel, R.G. & Likens, G.E. 1991. Limnological Analysis. (2nd Edition). Springer-Verlag, New York.

Whitton, B. A. & Rott, E. (Eds). 1996. Use of algae for monitoring rivers II. Institut fur Botanik, Univ. Innsbruck, Austria

Wilson, J.G. (Ed.). 1998. Eutrophication in Irish Waters. Dublin Royal Irish Academy.

Appendix 6.1: Genus/species list for each lake († = colony)

Chlorophyta	Atedaun	Cullaun	Inchiquin
Actinastrum	*	*	
Ankistrodesmus	*		*
Ankyra			*
Arthrodesmus		*	*
Asteriococcus	*		*
Botrycoccus†	*		*
Carteria	*		
Chlamydomonas	*	*	*
Chlorella	*	*	*
Chlorogonium		*	*
Closteriopsis	*	*	*
Closterium	*		*
Coelastrum			*
Coleochaete		*	
Cosmarium		*	*
Crucigenia	*		
Dictyosphaerium†	*		*
Eudorina	*		
Franceia	*		
Geminella			
Golenkina	*	*	*
Hafnimonas	*		
Klebsormidium			*
Microspora			*
Monorophidium	*		*
Mougeotia	*		
Oocystis	*	*	*
Pediastrum	*		
Pseudosphaerocystis	*		
Quadrigula	*	*	*
Scenedesmus	*	*	*
Staurastrum	*	*	*
Tetraedron		*	
Tetrastrum	*	*	
Treubaria	*		
Ulothrix			*
Xanthidium	*		*
No. of Species	26	15	23
Chrysophyta	**Atedaun**	**Cullaun**	**Inchiquin**
Chromulina		*	
Chyrsococcus			*
Dinobyron	*	*	*
Mallomonas	*	*	*
Synura			*
Tribonema			*
No. of Species	2	3	5
Pyrrophyta	**Atedaun**	**Cullaun**	**Inchiquin**
Ceratium	*	*	*
Gymnodinium		*	
No. of Species	1	3	1
Cryptophyta	**Atedaun**	**Cullaun**	**Inchiquin**
Chroomonas	*	*	*
Cryptomonas	*	*	*
Rhodomonas	*	*	*
No. of Species	3	3	3

Bacillariophyta	Atedaun	Cullaun	Inchiquin
Achnanthes	*	*	*
Achnanthidium	*	*	*
Asterionella	*	*	*
Bacillaria			*
Brachysira			*
Cocconeis	*	*	*
Cyclotella/Steph.	*	*	*
Cymbella	*	*	*
Diatoma	*		*
Encyonema		*	*
Eunotia		*	*
Fragilaria	*	*	*
Gomphonema	*	*	*
Luticola		*	
Navicula	*	*	*
Neidium	*	*	*
Nitzschia	*	*	*
Pinnumlria		*	
Placoneis		*	
Rhoplodia			*
Sellaphora			*
Surirella		*	*
Synedra	*	*	*
Tabellaria	*	*	*
No. of Species	14	20	21
Cyanophyta	**Atedaun**	**Cullaun**	**Inchiquin**
Anabeana	*	*	*
Aphanizomenon	*		*
Aphanothece	*		*
Chroococcus	*	*	*
Chroococcopsis		*	*
Coelospherium†		*	*
Elakothrix			*
Gleocapsa		*	*
Lyngba	*		
Merismopedia		*	
Micratinium		*	
Microcrocis†	*		
Microcystis	*		*
Oscillatoria†	*	*	*
Phormidium†	*	*	*
Pseudanbaena	*		
Rhabdoglea†		*	*
Snowella†		*	*
Stichcoccus	*		
Synechoccus	*		*
Tolypothrix			*
No. of Species	12	11	15
Euglenophyta	**Atedaun**	**Cullaun**	**Inchiquin**
Euglena	*	*	*
Lepocinclis	*		
Phacus	*		*
Trachlemonas	*	*	*
No. of Species	4	2	3

Appendix 6.2: Atedaun: Phytoplankton - cells per ml

	Nov-04	Dec-04	Jan-05	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Sep-05	Oct-05
CHLOROPHYTA												
Actinastrum	10											
Ankistrodesmus	40							10		10		
Asteriococcus												5
Botrycoccus†	15											
Carteria						40	25	10		10		
Chlamydomonas					60		15	70				
Chlorella				20		90	55	40				
Closteriopsis											10	
Coelastrum										40	90	
Crucigenia										20		
Dictyosphaerium†		20										
Eudorina						90	160					
Franceia			5									
Hafnimonas						15						
Monorophidium	15					20				90	5	35
Mougeotia										45		
Oocystis	15		5			40	25					
Pediastrum												5
Pseudosphaerocystis								90				
Quadrigula												100
Radiofilum								345				
Scenedesmus										140		60
Staurastrum	25	10		10								
Synechoccus	10									40		
Tetrastrum				20								
Treubaria	10											
Xanthidium						40						
PYRROPHYTA												
Ceratium										5		
EUGLENOPHYTA												
Euglena						10		40			15	
Lepocinclis	15											10
Phacus						10				15	15	10
Trachlemonas					10	130	10				20	
BACILLARIOPHYTA												
Achnanthes	15	10	35		20					5		
Achnanthidium	30		40							5		
Amphora												
Asterionella		50			40	440						
Cocconeis										10	10	10
Cyclotella/Steph		20				60						
Cymbella			30			15						
Diatoma						10						
Fragilaria						10						
Gomphonema												10
Navicula	5	5	10								5	5
Neidium			45									
Nitzschia						5						
Tabellaria						50						
CRYPTOPHYTA												
Chroomonas						50				10	25	15
Cryptomonas	15	15			30	50	5	5		5	40	25
Rhodomonas	10	15	10	70	90	145	90	35		30	230	75
CYANOPHYTA												
Aphanizomenon							140	110		70		
Anabeana							155	180		180		
Aphanothece		15										
Chroococcus		10										
Lyngba								145				
Microcrocis†	15	15								400		
Oscillatoria†		20					20	20				
Phormidium							360					
Pseudanbaena										65		
Stichoccus				20								
Panus										30		
CHRYSOPHYTA												
Dinobyron							175	5		45		
Tribonema											1305	
Identified Cells	245	205	180	150	255	1350	1235	1105	0	1270	1770	365
Species Richness	15	12	8	5	7	21	13	14	0	22	12	13
Shannon Weiner Index	1.12	1.01	0.82	0.66	0.72	1.05	0.90	0.91	0.00	1.03	0.44	0.96
Evenness value	0.95	0.93	0.90	0.85	0.85	0.79	0.86	0.84		0.79	0.41	0.83
Unidentified												
Unidentified colony	15	15	0	15	0	5	10	10	0	0	15	5
Unidentified filament	5	0	0	5	5	10	10	15	0	20	10	10
Unidentified single <10 µm	30	20	10	15	30	200	75	70	0	210	255	100
Unidentified flagellate < 10 µm	0	0	0	15	10	150	30	35	0	115	95	60
Total	50	35	10	50	45	365	125	130	0	345	375	175

Appendix 6.3: Cullaun: Phytoplankton - cells per ml

	Nov-04	Dec-04	Jan-05	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Sep-05	Oct-05
CHLOROPHYTA												
Actinastrum	140											
Arthrodesmus	10											
Closteriopsis										15		
Chlamydomonas	30		20	30	20	30	90	100	105	75	60	40
Chlorella						70						
Chlorogonium									10			
Coleochaete			5									
Cosmarium							10			25	5	
Golenkina											10	
Monorophidium	90					10		10	15	75	135	40
Oocystis			15	15							30	15
Quadrigula								60			185	35
Scenedesmus	50						60	60	40	200	365	120
Staurastrum					10					5		
Tetraedron										20	5	20
Tetrastrum	20			15								10
PYRROPHYTA												
Ceratium								15	5	5	5	5
Gymnodinium											15	
EUGLENOPHYTA												
Euglena				15								
Trachlemonas						20	10	20			45	25
BACILLARIOPHYTA												
Achnanthes			20				5		20			
Achnanthidium			15				10		15	15		
Asterionella	45	45	100		165		100	30		45	70	
Cocconeis							5		10	20	35	
Cyclotella/Steph					15	15	40	10		40	70	55
Cymbella									10	30		
Encyonema			15	5								
Eunotia			15									
Fragilaria		15			10	5		20	30	40	65	20
Gomphonema	5		10	5			10			15		5
Luticola										15		
Navicula			30	5	10				10			
Neidium						5	15					
Nitzschia						10	5					
Pinnularia			15									
Placoneis			10									
Surirella			15									
Synedra		45	55			15						120
Tabeleria						5						
CRYPTOPHYTA												
Chroomonas		15	90	10	65	30						5
Cryptomonas	15	20	15	20	45	45	5	30	10	30	10	40
Rhodomonas	45	55	70	70	75	125	55	40	40	95	30	90
CYANOPHYTA												
Anabeana									45	75	150	
Chroococcus						40						
Chroococcopsis							10		65	120		
Coelospherium†	10											
Gleocapsa						30						
Merismopedia								90		90		
Micratinium										75		
Oscillatoria†	20										20	5
Phormidium								10		10		
Rhabdoglea†								140				
Snowella†							10					
Panus								180				
CHRYSOPHYTA												
Chromulina						5						
Dinobyron						20	240	45	15	610	420	105
Mallomonas											20	
Identified Cells	960	390	1030	380	830	935	1130	1685	875	2880	3060	1405
Species Richness	18	12	23	16	15	23	24	23	22	30	27	24
Shannon Weiner Index	0.96	0.72	1.08	0.84	0.76	1.05	0.93	1.06	1.05	1.08	1.02	1.08
Evenness	0.84	0.93	0.88	0.84	0.79	0.85	0.72	0.86	0.88	0.77	0.76	0.80
Unidentified												
Unidentified colony	0	0	0	0	0	60	10	40	10	5	10	10
Unidentified filament	0	0	0	0	15	0	5	5	0	10	10	0
Unidentified single <10 µm	105	80	60	55	45	85	80	75	85	140	55	70
Unidentified flagellate < 10 µm	20	25	10	20	10	25	40	20	15	120	15	15
Total	125	105	70	75	70	170	135	140	110	275	90	95

Appendix 6.4: Inchiquin: Phytoplankton - cells per ml

	Nov-04	Dec-04	Jan-05	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Sep-05	Oct-05
CHLOROPHYTA												
Ankistrodesmus										135	200	
Ankyra											25	
Arthrodesmus										10		
Asteriococcus								20				
Botrycoccus†		15										
Chlamydomonas sp.	30			15	20	40	90	65	70	90	70	40
Chlorogonium										25		
Chyrsococcus				55								
Closteriopsis	25	5					10			10		
Closterium				10						10		
Coelastrum								120				
Cosmarium				10								
Dictyosphaerium†					10							
Golenkina								10		5		
Klebsormidium	330											
Microspora							150				80	
Monorophidium	130							10		430		
Oocystis					15		20			35		
Scenedesmus	820			20		20	70			700		40
Staurastrum	45	10			5					10	20	
Synechoccus											30	
Xanthidium										10		
Ulothrix												720
PYRROPHYTA												
Ceratium										5		
Gonyostomum	10											
EUGLENOPHYTA												
Euglena	15									40	50	
Phacus											25	10
Trachlemonas	30				10			35		20		5
BACILLARIOPHYTA												
Achnanthes	5						10		40			
Achnanthidium							5		30			
Asterionella	35					2155	5			30		
Bacillaria										20		
Brachysira				5								
Cocconeis	10					5						
Cyclotella/Steph	5	20	20	10		130			15	15	25	10
Cymbella						15						
Diatoma				25		30	10					
Encyonema				20								
Eunotia				5								
Fragilaria						40	15				45	30
Gomphonema		15	15		5	30						
Navicula				10		5						
Neidium					10							
Nitzschia	5			5		5						
Rhoplodia						10						
Sellaphora			10									
Suriella		15	15		15	10						
Synedra						10						
Tabelllaria	30					55		245				
CRYPTOPHYTA												
Chroomonas	15				55		20	25				25
Cryptomonas	60				10	10	45	30	115	20	30	30
Rhodomonas	125	10	45	40	100	50	140		60	150	80	75
CYANOPHYTA												
Anabeana				140				800	215	40	450	925
Aphanothece					800							
Aphanizomenon							300	200				
Chroococcus				20				60				
Chroocooccopsis	25									85		
Crucigenia							170					
Elakothrix						20						
Gleocapsa								135		30		
Oscillatoria†	30	10	15	5	15		60		20	15		10
Phormidium†	20											
Rhabdoglea †								10				
Snowella†								15				
Tolypothrix			150									
CHRYSOPHYTA												
Dinobyron	5						20	10	15	55		
Mallomonas										10	60	10
Synura	80										40	
Tribonema							750			100	200	
Identified Cells	3685	200	540	790	2140	5280	3010	3570	1145	4045	2560	3850
Species Richness	30	15	14	23	20	25	25	23	16	26	23	20
Shannon Diversity Index	0.89	0.88	0.62	0.96	0.46	0.40	0.96	0.84	0.79	0.98	0.82	0.65
Evenness	0.67	0.97	0.68	0.82	0.46	0.33	0.82	0.67	0.83	0.69	0.70	0.56
Unidentified colony†	0	10	10	5	20	5	5	10	0	0	5	5
Unidentified filament†	0	0	0	0	0	10	150	150	5	10	5	5
Unidentified single <10 µm	150	30	10	25	35	80	105	130	0	120	60	90
Unidentified flagellate < 10µm	60	20	5	10	10	30	45	75	0	55	70	30
Total	210	60	25	40	65	125	305	365	5	185	140	130

Appendix 7.1: Atedaun – Periphyton counts

	Jan-05	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Sep-05	Oct-05
CHLOROPHYTA										
Botrycoccus colony†								2		
Bulbochaete		4			6		3			2
Chaetophora		16	8				8	6	8	
Chlorella				12						
Chlorococcum								12		
Chlamydomonas sp					2		5		5	
Cosmarium					3					
Crucigeniella				6			8	8		8
Geminella					2					
Haematococcus								12		
Hydrodictyon†				1						
Klebsormidium					6		8	11		
Mougeotia					6		4			
Microspora				2						8
Oocystis		3			2		12	9		5
Oedigonium							6	6	13	2
Pleurastrum†								2		
Protoderma†									2	
Scenedesmus		12		12	60		16	12	20	64
Staurastrum		2								
Stigeclonium							26			
Tetraselmis				4						
Ulothrix										9
BACILLARIOPHYTA										
Achnanthes		18	13	8	13		18	4	10	11
Achnanthidium		16	11	11	16		22	6	8	8
Amphora		4	7		3					
Asterionella				13						
Brachysira			8							
Cavinula			3							
Cocconeis		4	4	6	4			3	4	
Cyclotella/Steph				3	6					
Cymbella		21	16		11			14	8	21
Denticula		3								3
Diatoma				6						9
Diploneis					3					
Encyonema		4								5
Eunotia			5	5						
Epithemia					4			3	3	4
Gomphonema		28	18	24	12		12	6	16	4
Grongosira								12		
Luticola		2								2
Meridion		3	3	3	6					
Navicula		22	13	16	22		11	92	12	23
Neidium		6	3	12	8					5
Nitzschia		18	14	23	16		11	5	11	18
Pinnularia		2		4	8		6	3	6	2
Placoneis			16							4
Rhoicosphenia		2	16	11	6				4	2
Stauroneis		6	4	3	1		5	2	3	4
Sellaphora					4				11	2
Suriella		6	4	5	4				1	3
Synedra					6			3	11	3
Tabellaria				21						
Tetracyclus								8		
Tryblionella									3	
CYANOPHYTA										
Anabeana				11						
Aphanothece†		2			2			3	8	
Aphanizomenon					6				8	
Aulocaseira				6						
Calothrix							3	8	3	
Chroococcus		24	12	30	42		24	32	45	
Chroococcus colony†		3		2	4		6	7	4	
Chroococcopsis				16					6	16
Coelospherium†								2		
Crucigenia					7					
Dichothrix †									4	
Gleocapsa†				3	3		2	11		
Homeothrix			4							
Hydrococcus								16		2
Lyngbya > 10 um†		2	24	2			11	2		
Lyngbya < 10 um†		5	11	7			3		16	3
Oscillatoria >10 um†		5	11		4		8	3	1	5
Oscillatoria <10 um†		2	10	3				2	3	1
Phormidium >10 um†		3	12		6		5	1	2	
Phormidium < 10 um†		3	6				2	2	12	
Pleurocapsa		9							10	4
Rivularia†							4	3	4	
Schizothrix†			6		20		11		3	
Stigonema			4				4			
Symploca			12							
Synechococcus		9	8	1			6		8	6
Synechococcus colony†		2					2	2	5	
Tolypothrix†							11			
Total identified		271	286	288	334		283	335	301	259

Total unidentified		29	33	40	36		33	30	27	11

Appendix 7.2: Cullaun – Periphyton counts

	Jan-05	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Sep-05	Oct-05
CHLOROPHYTA										
Arthrodesmus								2		
Asterococcus								14		
Bulbochaete				3					2	
Characium									3	3
Chladophora							11	5		
Chlorella	8									
Chlorococcum								8		
Dictyosphaerium								20		
Klebsormidium	14		26	15	5					
Monorophidoium									2	
Mougeotia						5				
Oocystis										8
Oedigonium			3	5		14	9			2
Pediastrum				28		71	38			
Planktosphaeria†								1		
Scenedesmus					28	4	68		20	48
Spirogyra			24							
Sphaerellopsis								6		
Stigeoclonium	109		6							
BACILLARIOPHYTA										
Achnanthes		36	19	10	10	28	10	5	5	16
Achnanthidium		12	10	11	9	29	9	12	11	19
Amphora	2	3	8	5		2			7	
Aulocseira				8	16		8			9
Brachysira		2		5	5	4	2			
Cavinula			11				2			
Caloneis				2			6			
Cocconeis		3		5	1		3	3		
Cyclotella/Steph	2		3		2			1		
Cymbella	6	12	50	25	30	16	15	22	30	25
Denticula			10	5	7	14		9		11
Diadesmus				4						
Diatoma	3			6	9			5		8
Diploneis					5		6			
Encyonema			5	8	5	13	2	6	8	3
Epithemia			9			2		3	6	5
Eunotia	1	6	3		5		3			
Fragilaria						5				11
Frustulia	2									
Gomphonema	4	38	28		16		13	11	9	5
Grongosira	11									
Luticola				2	2					
Martyana			4	7	3					
Meridion					4					
Navicula	6	14	13	21	40	17	16	16	16	15
Neidium				5	5	1	8	5	12	7
Nitzschia		3	10	29	35	15	10	20	14	17
Pinnularia	1	8	4	5	2	5		6	6	3
Placoneis		6								
Punctastriata										3
Rhoicosphenia	2					6	7			2
Stauroneis				5	2	4				
Staurosirella		3								4
Sellaphora			12				5		3	
Semiorbis		14								
Suriella		6				2				1
Synedra	3	4		11	7	7	3	3	11	17
Tetracyclus					2					
CYANOPHYTA										
Aphanothece†						1	3		3	2
Aphenocapsa†				1					7	
Calothrix	35	60		18						4
Chroococcus		80			2	20	18	48	36	16
Chroocooccopsis	16					4		26		
Cylindrospermum				2						
Dichothrix†									2	
Geminella			20							
Gleocapsa	11				12			23	10	16
Gleothrichia	2									
Gomphosphaeria				12						
Homeothrix							6			
Lyngbya >10 um†	6	4	1		2		2	4	7	3
Merismopedia								62	32	
Oscillatoria† > 10um†	1	2		6	6		8	7	8	2
Phormidium > 10 um†				5	8			1	6	3
Pleurocapsa		5		2			4	6		
Rivularia†		5		4		1	2			
Schizothrix†							9			
Scytonema	44									
Synechococcus	9					18	9		21	11
Total identified	298	326	279	280	285	308	315	404	297	299
Total unidentified	20	23	35	46	59	40	47	52	34	45

Appendix 7.3: Inchiquin – Periphyton counts

	Jan-05	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Sep-05	Oct-05
CHLOROPHYTA										
Aphanochaete						18				
Bulbochaete					16	11	9			
Chaetophora			81							
Chlorella		6 ?								
Chlamydomonas sp				8	9	6				
Closterium									1	
Cosmarium		4			2	6	2	3	2	
Drapnaraldia		50								
Geminella							18			
Klebsormidium										16
Oocystis								12		
Oedigonium		16		12	12	12				
Pediastrum		60				45	16			45
Scenedesmus				14	36	12	18	24	56	
Staurastrum	4	4	2		2					
Stigeclonium	22			15		6				
BACILLARIOPHYTA										
Achnanthes	18	7	9	21	18	17	41	33	45	23
Achnanthidium	12	6	8		11		21	28	36	20
Amphora		5	3							4
Asterionella				8						
Aulocseira									9	
Brachysira						2	6		6	8
Caloneis	3			4						
Cavinula			2							
Cocconeis		3	1							6
Cyclotella/Steph	4	2	3							
Cymbella	23	11	26	11	4	6	18	4		12
Denticula				4		2	4		6	
Diadesmus		6								
Diatoma		2	5	4	1	2		2		
Diploneis									6	
Encyonema		3	4	5			6		3	14
Eunotia		9		2	4		2	4		17
Fragilaria							2			
Gomphonema	26	25	21	11	8	8		3		22
Grongosira	8				11					
Licmorpha			8							
Luticola			6	2	2					
Meridion				6					4	
Navicula	16	15	25	24	22	12	17	6	10	21
Neidium							3			
Nitzschia	16	8	7	21	19	4	13	12	18	16
Pinnularia	4	3	2	4	6		9	4	4	
Placoneis			9	3	3	2	5		18	
Rhoicosphenia	4	2		3		4		6		6
Stauroneis	5	9	14					2		5
Sellaphora	2			4		2				
Suriella		4		6			5			
Synedra	6	1					12		32	11
Tabeleria		2					2		2	5
Tetracyclus			3							
Tryblionella			12							
CYANOPHYTA										
Aphanothece†					3	2				
Aphanizomenon				17				18		16
Calothrix			20							
Chroococcus	23	19	18	12	28	13	11	16		
Chroococcus colony†			1	1	3	2		12		
Chroocooccopsis				3	11		16	21		
Coelospherium			8							
Dichothrix †	8									
Gleocapsa	2				4					
Homeothrix	8									
Hyella				11		20				
Hydrococcus								16		
Hydrocoleum						12				
Lyngbya > 10 um†	41		2			4	6	16	18	12
Lyngbya < 10 um†			3	11		18		2		
Merismopedia							16			
Oscillatoria >10 um†	5	2	8	16	6	8	11	26	4	5
Oscillatoria <10 um†				2	2	3		5		
Phormidium >10 um†	5	3		16	4	2	5	5		
Phormidium < 10 um†				1	2	2		7		
Pleurocapsa	14			16	19	12		16		
Pseudanbaena	8									
Rhabdoderma						9			8	
Rivularia†			3		16		2	6		
Schizothrix†						11				
Scytonema						5				
Synechococcus							6	2	4	3
Tolypothrix									8	
Ulothrix										13
Total identified	287	281	302	300	284	300	302	311	300	300
Total unidentified	18	23	27	25	29	53	53	43	39	32

Appendix 8 CCA taxa code numbers and taxon names of 61 algae with a relative abundance greater than 5% in at least one sample. * Signifies colonial form

CCA Code	Taxa name	CCA Code	Taxa name
1	*Achnanthes*	32	*Lepocinclis*
2	*Achnanthidium*	33	*Lyngba*
3	*Actinastrum*	34	*Mallomonas*
4	*Anabeana*	35	*Merismopedia*
5	*Ankistrodesmus*	36	*Microcrocis**
6	*Aphanizomenon*	37	*Microspora*
7	*Aphanothece*	38	*Monorophidium*
8	*Asterionella*	39	*Navicula*
9	*Botrycoccus**	40	*Neidium*
10	*Chlamydomonas*	41	*Oocystis*
11	*Chlorella*	42	*Oscillatoria**
12	*Chroococcus*	43	*Pannus*
13	*Chroococcopsis*	44	*Phormidium*
14	*Chroomonas*	45	*Pseudanbaena*
15	*Chyrsococcus*	46	*Pseudosphaerocystis*
16	*Closteriopsis*	47	*Quadrigula*
17	*Coelastrum*	48	*Radiofilum*
18	*Crucigenia*	49	*Rhabdoglea**
19	*Cryptomonas*	50	*Rhodomonas*
20	*Cyclotella/Steph*	51	*Scenedesmus*
21	*Cymbella*	52	*Staurastrum*
22	*Diatoma*	53	*Stichococus*
23	*Dictyosphaerium**	54	*Surirella*
24	*Dinobyron*	55	*Synedra*
25	*Encyonema*	56	*Tabeleria*
26	*Eudorina*	57	*Tetrastrum*
27	*Euglena*	58	*Tolypothrix*
28	*Fragilaria*	59	*Trachlemonas*
29	*Gleocapsa*	60	*Tribonema*
30	*Gomphonema*	61	*Ulothrix*
31	*Klebsormidium*		