Nutrient Levels and the Zebra Mussel Population in Lough Key

Prepared for the Environmental Protection Agency

Authors:

Frances Lucy, PhD
Monica Sullivan, PhD
Dan Minchin, PhD

Institute of Technology, Sligo

December 2005

ENVIRONMENTAL PROTECTION AGENCY
An Ghníomhaireacht um Chaomhnú Comhshaoil
PO Box 3000, Johnstown Castle, Wexford, Ireland
Telephone: +353-53-606000   Fax: +353-53-60699
Email: info@epa.ie   Website: www.epa.ie

ACKNOWLEDGEMENTS

This report has been prepared as part of the Environmental Research Technological Development and Innovation Programme (ERTDI) under the productive Sector Operational Programme 2000-2006. The programme is financed by the Irish Government under the National Development Plan 2000-2006. It is administered on behalf of the Department of the Environment, Heritage and Local Government by the Environmental Protection Agency which has the statutory function of co-ordinating and promoting environmental research.

We wish to acknowledge the following people who assisted with various practical and theoretical aspects of this project; Dr Jim Bowman, EPA; laboratory staff at the EPA, Dublin; Ms Sharon Duggan; Ms Audrey Marshall; Ms Karen O' Mahony; Mr Justin Lohan; technical staff at the School of Science, Institute of Technology, Sligo; Mr Peter Walsh, Lough Key Boats; Mr Ivor Marsh, Monterrey Software; Mr Myles Woods; Mr Hugh Sullivan; Mr David Dodd; Mr John O' Gorman, Roscommon County Council; Mr John Casey, Lough Ree-Lough Derg project; Mr. Des Gillett, Tara Cruisers; and Drs Lyuba Burlakova and Alexander Karaytayev of Stephen F., Austin State University, Nacogdoches, Texas.

NUTRIENT LEVELS AND THE ZEBRA MUSSEL POPULATION IN LOUGH KEY

FULL REPORT

CONTENTS

List of Figures

List of Tables

List of Plates

Summary

The zebra mussel (*Dreissena polymorpha*) is an aquatic invasive species, which spread to Lough Key, Co. Roscommon, from the lower Shannon in the late 1990s. The mussels have been monitored in this 9km^2 lake each year since 1998. By 1999 the population estimate was 6 billion ($6x10^9$) with high cover of zebra mussels on stones in near-shore areas of the lake. This project was a three-year study (2001-2003) on the impact of nutrients on the zebra mussel population in Lough Key (2000-MS-5-M1: ERTDI programme), which included some previous data from 2000.

Zebra mussels are effective filter feeders, with high individual clearance rates of phytoplankton, Cyanobacteria and other particles. Successful colonisation of a lake results in increased transparency and decreased chlorophyll levels and often a consequent decrease in total phosphorus. Since 1999 these changes have been noted in Lough Key. Transparency and chlorophyll levels indicate an improvement in trophic status (to oligotrophic) but total phosphorus levels are still within the mesotrophic range and have not reached limiting levels. These direct impacts create problems in classifying lakes according to existing (OECD) and developing (Water Framework Directive (2000/60/EC) classification schemes.

The construction of the new Boyle sewage treatment plant with a phosphorus removal system has reduced the loading of total phosphorus to Lough Key. It was believed that the reduction in phosphorus loadings could have a limiting effect on zebra mussels in Lough Key, due to a consequent reduced production of phytoplankton. It is not possible to separate the nutrient impacts this species has had on lake water quality from that due to the new sewage treatment plant.

The project aimed to quantify the total number and biomass of zebra mussels and also to assess any changes to the population during the course of the study. Relevant water parameters and phytoplankton samples were analysed; direct ecological changes were also noted during the project.

Zebra mussels were studied at all stages of growth from larva/veliger stage, through juvenile settlement and most intensively in the juvenile and adult stage (0-3 years). The total number of adult zebra mussels in the lake was estimated at 34 billion

(34×10^9) with a total biomass of 4.4×10^6kg. This number is believed to relate to a more effective method of population estimate, rather than any real increase since 1999. This population is capable of filtering the entire volume of Lough Key in a 10 - day period.

Biomass estimates taken in 2001 and 2003 were not significantly different – this indicates that changes in total phosphorus did not limit the zebra mussel population during the course of the study. Food availability appears to be the main density-dependant limiting factor in the lake, as many stoney areas are not fully colonised.

Ecological changes noted during the study included the extirpation of the native duck mussel (*Anodonta anatina*) the reduced usage of the common reed (*Phragmites australis*) as a substrate by the zebra mussels and increased growth of aquatic plants and benthic algae.

Chapter 1. Introduction

1.1 Overview of Chapter

Chapter 1 provides the background to the project and also the rationale for carrying out research on the zebra mussel populations in Lough Key. There is an overview of the zebra mussel invasion history, life cycle and its impacts on water quality. The chapter also includes a brief review of Lough Key as a study area. The general background to the project is introduced with associated objectives, targets and methodologies. The project management team is also outlined and the role of each participant given.

1.2 The Zebra Mussel (*Dreissena polymorpha*)

1.2.1 Invasion History and Impacts

The zebra mussel (*Dreissena polymorpha)*, is a freshwater bivalve mollusc, which attaches to hard substrates by byssal threads. It is native to the Black Sea and Caspian Sea basins and spread through much of Europe almost two hundred years ago with the development of canal systems. By 1824 the species had become established in Britain. In North America the first recording of the zebra mussel was in the Great Lakes in 1986. Within seven years it had spread to eighteen states in the USA and two provinces in Canada (Johnson and Padilla, 1996) and further colonisation is ongoing (New York Sea Grant, 2003).

In Ireland the initial introduction of the zebra mussel is believed to have taken place in 1994 in the lower Shannon system (McCarthy *et al.*, 1998; Minchin and Moriarty, 1998). Imported second-hand leisure craft were the most likely vector for their introduction. Live zebra mussels of English origin, were found on the hulls of leisure craft on arrival in Ireland, over the period 1997 to 2001. Irish zebra mussels have also been genetically linked to English populations (Pollux *et al.*, 2003, Astenei *et al.*, 2005). Once established, significant zebra mussel settlement took place on native leisure craft and these mussels were carried to the upstream Shannon navigation via locks and swing bridges (Minchin *et al.*, 2002a). Large populations now exist in Loughs Derg, Ree, Bofin and Key. By 1996 zebra mussels had become established in Lower Lough Erne (Rosell *et al.*, 1999) and in the following year were present in Upper Lough Erne.

Further spread continued in the early years of the new millennium. At least 55 water bodies in Ireland are now known to be infested including Loughs Sheelin, Gill and Derravaragh. Investigations in the summer of 2003 indicate a number of potential vectors in the spread of zebra mussels in Irish lakes; the primary vector is believed to be the overland movement of boats fouled by zebra mussels (Minchin *et al*., 2003).

The growth and spread of the zebra mussel in Ireland has shown the species to be an aggressive competitor for substrate space. It is also an effective filter feeder with high individual clearance rates (Horgan and Mills, 1997), which has subsequent implications for both water quality and ecosystem processes. In addition to these impacts there is a financial cost to man, as this aquatic nuisance species is a very effective biofouler capable of blocking up water abstraction pipes, damaging boat engines, sinking navigational buoys and creating other damage.

1.2.2 Life cycle

The zebra mussel life cycle consists of a relatively sessile adult phase and a planktonic, free-living larval stage. Sexes are separate, with occasional hermaphrodites and mussels usually become sexually active in the summer season, at one year old. In Lough Derg, gonads and gamete development were observed in mussels in all months and in all sizes of mussel from 6.0mm up to 25.9mm (Juhel *et al.*, 2003). In Europe some survive as long as nine years, but usually live from three to five years (Marsden, 1992). Many size distributions have been taken at different times of the year throughout the Shannon navigation (Minchin *et al.*, 2002b). It would seem from the largest individuals found (38 mm) that the species may exceed a three year life cycle in Ireland, but that most of the population survive between two and three years and these spawn each summer from the 1+ stage onwards.

Egg production estimates per female mussel vary from 30,000 to 1.6 million (Mackie *et al.*, 1989; Borcheding, 1992) and fertilisation occurs externally (Nichols, 1996). Temperatures of 15^{o}C have been reported as a threshold for appearance of larvae (Karatayev, 1998). Other factors may also be involved, e.g. food availability, current patterns and other limnological variables (Haag and Garton, 1992). Embryological development follows the typical bivalve pattern progressing through swimming blastula, trochophore, straight-hinge (D) larva, umbonal (veliconcha), pediveliger (settling stage) and plantigrade (juvenile, postveliger, spat) stages (Conn *et al*., 1993). Ackerman *et al*. (1994) reviewed published sizes of the various developmental stages of *Dreissena polymorpha* and found that straight-hinge (D) larvae can range in height from 70 to 160µm, umbonal larvae from 120 to 280µm, pediveligers from 167 to 300µm and plantigrades from 158 to 500µm.

Relatively strong correlations have been found between temperature and food supply and the rate of growth in zebra mussels (Chase and Bailey, 1999). Zebra mussel larvae are distributed unevenly, both vertically and horizontally in the water column, which results in a clustered or patchy distribution of larvae. Maximum density of veligers occurs at depths of 3-7 m (Mackie and Schloesser, 1996). Veliger densities as high as 400,000m^{-3} have been observed in Europe and 100,000m^{-3} in Lake Erie (Marsden, 1992). Pediveligers actively select substrates on which they settle by secreting byssal threads and undergoing metamorphosis to become plantigrade mussels. The developing juvenile acquires a mussel shape, with the distinctive banded pattern and begins to form its feeding apparatus at approximately 1 mm in size (Ackerman, 1994). The amount of time required for development of a fertilised egg to a juvenile varies inversely with water temperature and has been reported in the literature as varying typically 8-15 days in American waters (Marsden, 1992) and 7-10 days in Europe at favourable temperatures (Hillbricht-Ilkowska and Stanczykowska, 1969). Typical larval development time for Irish waters is between two to three weeks in the July/August period, with settling out occurring from 200-370 µm (Lucy and Sullivan, 2001). Mortality in larvae and newly settled individuals has been reported at levels of 20% up to 100%, most occurring late in the cycle during metamorphosis and settlement (Nichols, 1996). The first year of significant spawning of zebra mussels in Lough Key was 1998.

1.2.3 Substrates for Zebra Mussel Settlement

Following the settlement zebra mussels typically attach to each other often forming dense colonies, commonly 4-6cm thick, with several layers of zebra mussels attached to each other by byssal threads (Tuchman *et al*., 2004). These three dimensional dense aggregations are often known as druses; and may be attached to a hard substrate, commonly stone on the benthos, or in the case of soft substrates form a loose conglomerate of zebra mussels, which originally settle on a small particle of sand or shell. In general oldest individuals occupy the centre of the druse, while towards the outermost regions the age decreases, due to the successive settlement of younger individuals on older ones (Stanczykowska, 1964). North American and European research experience has shown that mussels can make bysssal attachment to any firm surface material including:

- Natural substrates, e.g. stone, wood, macrophytes and the shells of native Unionid bivalves. While it was initially believed that a firm substrate was critical for settlement, studies in Lake Erie have shown successful colonisation in areas where the actual substrate is a soft, muddy sediment (Berkman *et al*., 1998).
- Other substrates usually introduced by man, e.g. man-made navigational structures such as boat hulls, anchors and chains; concrete; plastic; fibreglass, metal; vinyl; glass and cloth. High settlement densities on manmade structures are financially costly, requiring strategic management and control strategies.

While initial primary larval settlement dominates the settlement patterns of the zebra mussel, secondary settlement may also occur in plantigrade, juvenile or adult zebra mussels. Translocation can take place to new locations via a number of mechanisms including 'crawling' onto substrates and surface films, drifting using specially secreted threads, floating on air bubbles and rafting on macrophytes and other flotsam (Martel, 1993; Ackerman, 1995). Probably the most important means of secondary settlement is by translocation on boats and barges.

1.3 Lough Key as a Study Area

Lough Key is situated in the Upper Shannon catchment (G830 060) and is located on the Boyle River, which flows into the Shannon above Carrick-on-Shannon. The Lough Key catchment is a mixture of sandstone, shale and limestone, resulting in a wide variation in ionic content of the waters of the inflowing streams. Lake water is of high ionic content, alkaline and strongly coloured, with low transparency. Lough Key is currently classified as mesotrophic, with reduced planktonic algal growth. It is believed that the presence of zebra mussels may be the principal factor in this reduction from eutrophic levels (McGarrigle *et al.*, 2002). This lake is suitable as a lake for zebra mussel sampling due to a number of factors:

1. The lake is small (9 km^2) with 50% of the lake ranging from 2-5 metres in depth (mean depth 4.5m) and only one major inflow and outflow (the Boyle River).

2. Zebra mussel population studies have been carried out since the early stages of invasion in 1998, the first year of population expansion in this lake.

3. Water quality parameters associated with zebra mussels have also been monitored in conjunction with the above. These include chlorophyll *a*, transparency, molybdate reactive phosphorus and total phosphorous.

4. Significant changes in lake water quality can be directly associated with increasing zebra mussel populations between 1998 and late 2000. From 2001 onwards the new phosphate removal facilities in Boyle Sewage Treatment Plant (STP) may also have contributed to such changes. EPA datasets for water quality prior to zebra mussel invasion are available for baseline comparisons. Changing trends in water quality or in phytoplankton communities (e.g. *Microcystis*) can thus be monitored.

5. Zebra mussel populations can be examined on a number of substrates - stoney substrates, reed beds and *Anodonta* shells. In common with many Irish lakes the littoral zone substrate of Lough Key is often stoney. Some of the perimeter of the mainland and islands is also fringed with reed beds. No living *Anodonta* have been found in the lake since November 1999, with mortality due to extreme fouling of the shells by zebra mussels. Impacts of the zebra mussel on other native bivalves have been researched extensively both in Europe and North America (Lewandowski,1976; Ricciardi *et al*., 1998; Schloesser *et al*., 1996; Karatayev *et al*., 1997). Negative impacts are believed to be due to the smothering of the unionid siphons, prevention of valve opening and closure, and by interference with normal feeding patterns (Ricciardi *et al*., 1995).

1.4 Zebra Mussel Impacts on Water Quality and Phytoplankton

The key indicator in assessing the water quality or trophic status of a lake is the determination of the extent of plant growth, both planktonic and benthic, in the water. In the case of the planktonic forms, this assessment is most commonly expressed in terms of the concentration of the plant pigment chlorophyll. The extent of planktonic algae is a function of the nutrient levels, principally phosphorus, present in the lake and also on the extent of grazing by other organisms.

Up to relatively recently zooplankton and fish were the only grazers of planktonic algae in Lough Key. A decade or so ago, a new and more significant grazer, the zebra mussel (*Dreissena polymorpha)*, was introduced to the Shannon system. Zebra mussels are extremely efficient filter feeders and this has been well documented in both European and North American literature. Zebra mussels draw water through their mantle cavity, but use only a portion of the seston particles for their digestion, while the rest is agglutinated as pseudo faecal pellets and ejected (Stanczykowska and Planter, 1985). Many of the studies on zebra mussel ecology have concentrated on the types and size of phytoplankton consumed by zebra mussels (Sprung and Rose, 1988; Holland, 1993; Jack and Thorp, 2000; Wilson, 2003; Dionisio Pires *et al.,* 2004). As zebra mussels can readily reject food particles as pseudofaeces, research has also assessed whether this species is selective in its feeding habits (Ten Winkel and Davids, 1982; Vanderploeg *et al.,* 1996). Food selectivity is an important issue because Vanderploeg's study claimed that zebra mussels selectively reject toxic strains of the cyanobacteria, *Microcystis*. This could lead to strain dominance in algal blooms with consequent public health issues (Chorus and Bartram, 1999).

Zebra mussel filtering and/or excretion activities have also likely contributed to major changes in relative abundance of phytoplankton species. In many waters the most apparent change has been the new occurrence of cyanophyte (blue-green algae) blooms. One likely theory is the selection of more desirable algae species with rejection of less palatable cyanophytes (Nalepa *et al*., 1999). Observations using micro cinematography show that zebra mussels reject the cyanophyte, *Microcystis* as pseudofaeces (Vanderploeg *et al*., 1996). Cyanobacteria were generally the dominant organisms in the plankton in Lough Key in 1998 and 1999, with *Microcystis* forming the most important constituent of this population (Bowman, 2000). *Microcystis* is associated with toxic blooms as this and some other cyanobacteria genera produce a potent class of hepatotoxins called microcystins that can poison aquatic organisms as well as wildlife, domestic animals and humans that drink or ingest algae in the water (Carmichael, 1994). Some strains of cyanobacteria in Irish lake blooms have been shown to be toxic in nature (Metcalf and Codd, 2004). Therefore implications exist for water-based leisure activities and potable water supplies.

Zebra mussel adults are capable of filtering particles ranging in diameter from 0.7 µm (Sprung and Rose, 1988) to 1.5 mm (Horgan and Mills, 1997). Ingestion is selective and unsuitable particles are rejected as pseudofaeces via the exhalent siphon (TenWinkle and Davids, 1982). These particles include phytoplankton, cyanobacteria, zooplankton, microorganisms, detritus and inorganic suspended solids. Thus the zebra mussel is capable of removing abiotic as well as biotic material from the water. By removing large amounts of suspended matter, populations of zebra mussels have the ability to alter transparency and plankton abundance (Holland, 1993). The increase in light penetration in the water column creates conditions favourable for benthic algal and other macrophytic growth.

The filtering activity of zebra mussels will have the direct effect of reducing nutrients, which are associated with particles and plankton. These are either assimilated into zebra mussel biomass or rejected and deposited on the substrate as faeces and pseudofaeces. As a result, energy is shifted from the pelagic to the benthic zone and changes occur in the normal pathways by which nutrients are utilized and cycled (Nalepa *et al.*, 1999).

Ranges of the mean summer total phosphorus, chlorophyll *a* and transparency concentrations in Lough Key for 1976 are available in Toner, 1979. Data for 1986 (An Foras Forbatha) and 1995-1997 are in Bowman (1998). These reports indicate a decline in trophic status between 1986 and 1997. There was a subsequent improvement in levels from 1998 onwards with total phosphorus concentrations in the summer of 1999 much reduced from 1996 and 1997 (Bowman, 2000).

A significant reduction in annual mean total phosphorus concentrations was recorded in Lough Erne during 2000 and 2001, from 1998 levels (Maguire *et al.*, 2003), following invasion of zebra mussels. This trend in total phosphorus levels was in line with results obtained in some North American (Johengen *et al.*, 1995; Nalepa, 1999) and European studies (Stanczykowska and Planter, 1985).

1.5 Position of Project within National Development Plan (2000-2006)

This three-year project originally titled 'The impact of nutrients on the zebra mussel populations in Lough Key' (2000-MS-5-M1) officially commenced on December 1, 2000 as a three-year medium scale project for the EPA. It was funded by the Environmental RTDI Sub-Measure of the Operational Programme for the Productive Sector (2000-2006) as part of the National Development Plan (2000-2006).

The aims of the measure relevant to this particular project were to:

- Contribute to a better environment by delivering applicable and relevant research data and information based on high quality science and technology
- Generate data, information and knowledge for improved management of the environment
- Develop new techniques, methods and systems for measuring, recording and predicting the quality of the environment. This is in line with the development aims of the Water Framework Directive (2000)

1.6 Background to Project

1.6.1 Introduction

The monitoring of the zebra mussel populations in Lough Key commenced in 1998 (Lucy, unpublished) and was supported through 1999 by the EPA with a small scale project which established baseline information on the existing populations in the lake (Lucy and Sullivan, 2001). Simple maps were prepared of zebra mussel distribution in the lake as well as information on their adult and juvenile densities. An estimate was also made of the filtering capacity of the existing population. A further independent survey was carried out by the authors in the summer of 2000. This was considered vital as valuable information would be lost if there was a break in the continuity of the investigation. A research extension in terms of scale, technology and coverage was fortunately provided under the ERTDI programme.

1.6.2 Link Between the Zebra Mussel Population and Nutrient Inputs

The zebra mussel population in Lough Key is supported by suspended material in the lake water. This material consists of organic matter, planktonic algae and cyanobacteria. The latter two components are sustained by phosphorus, believed to be chiefly derived from the waste discharge at Boyle Sewage Treatment Plant (Boyle

STP). This STP was upgraded in Autumn 2000 to include a phosphate removal system. When the new plant was commissioned there should have been a marked reduction in the nutrient loading on the lake, leading to depleted quantities of food available to the zebra mussels. This hypothesis provided a research opportunity in Lough Key to investigate the combined interactions between the reduced phosphorus input to the lake with the planktonic algae, the cyanobacteria standing crop and the zebra mussel (*Dreissena polymorpha)* populations.

There has been a considerable investment made in the River Shannon catchment for waste treatment facilities (including phosphorus removal), with the ultimate aim of reducing nuisance algal and plant growth in the lakes. It is therefore important that all the processes impacting on this growth are understood and quantified. There is a popular view that there may be no need to reduce phosphorus losses to waters in the River Shannon system as zebra mussels will take care of the ensuing algal growth. This misconception needed to be challenged with facts arising from a systematic study.

Building on the 1998-2000 datasets, this project area was targeted to add value to the initial study and to provide information on the relative contributions of the zebra mussels and proposed remedial measures to changes in water quality. The aim was also to provide a useful insight into how, and if the zebra mussel populations in Lough Key could be affected by these changes.

1.7 Project Objectives

The main objective of this project was to develop a clear understanding of the role of the zebra mussel in lake ecosystems and in particular the relationship between phosphorus concentration, zebra mussel populations and the trophic status of Lough Key.

1.8 Key Areas of Research

Throughout the course of research this project focused on three key areas:

- Estimation of zebra mussel populations (biomass and numbers) in Lough Key associated with different substrata and depth zones

- Assessment of changes to water quality in Lough Key due to zebra mussel filtration and the new phosphate removal system (Boyle STP)
- Evaluation of changes in phytoplankton and cyanobacterial standing crops in Lough Key

1.9 Project Tasks and Associated Methodologies

- Substrate and bathymetric mapping of Lough Key (2001): This provided a depth (bathymetric) chart and a sediment map of the lake based on an acoustic Roxann^{Tm} survey (Seabed Surveys Ltd.). This survey provided information on the different consistencies of the lake sediments and the extent of substrate types suitable for zebra mussel colonisation in Lough Key. The different substrate areas were then further investigated, by grab sampling, snorkelling or diving, to confirm their composition and the extent of their suitability. The lake area at different depth intervals was estimated using this data. Underwater video survey work was also used to map shallow areas. A zebra mussel habitat map of Lough Key was determined based on different substrate types.
- Monitoring of zebra mussel populations (larval, juvenile and adult) in littoral, open water and benthic zones of Lough Key both before and after the commissioning of the new STP at Boyle (2000-2003): this involved the use of plankton nets, settlement plates, grabs, quadrats, scrapers, an underwater video camera, and snorkel and dive surveys. Adult zebra mussels were monitored for biomass and total number on identified lake substrates, aquatic plants and on unionid shells. Total number and biomass of zebra mussels in Lough Key was assessed using a transect survey (2002).
- Measurement of light penetration and chlorophyll levels in the lake to assess the impact of the zebra mussel population on light penetration in the lake and on the biomass of phytoplankton (2000-2003): this was monitored using secchi disc and standard EPA chlorophyll *a* methods, respectively. Temperature was measured using an alcohol thermometer and also with a data logger.
- Collation and analysis of relative phytoplankton and cyanobacterial abundance from EPA datasets (2000-2003): data was examined to see whether there were

any changes in frequency of varying taxa to assess the impact of a possible reduction in the Lough Key phosphorus loading on the planktonic algal and cyanobacterial biomass in the lake.

- Input and analysis of phosphorus data from (1) Boyle Sewage Treatment Plant (P loadings to lake) (Roscommon County Council data), (2) Boyle River upstream and downstream of the treatment plant (Lough Ree-Lough Derg project data) and (3) Lough Key data (EPA monitoring programme)(2000-2003): These data were analysed to determine changes in water quality following the commissioning of the new phosphate removal system at Boyle.
- Statistical testing of zebra mussel datasets for a possible response due to the commissioning of the new treatment plant: this was achieved by statistical analysis of multiple sample results from before and during the course of this research project (2000-2003).

1.10 Project Management and Role of Participants

Table 1 outlines the project management structure in terms of project tasks and deliverables, giving a timescale for each participant's role. Technical reports were submitted every six months, seven in all, during the course of the project to report progress on specific tasks, timescales and results.

Table 1.0 Project participants, roles and associated timescales

Project Participant	Role	Timescale
Mr Pat Timpson	Project Coordinator	2000-2003
Ms Frances Lucy	Lead researcher. Intensive and extensive lake-water and zebra mussel monitoring, laboratory analysis, project co-ordination, report writing. BSc Supervisor of student projects on larval/veliger stage.	2000-2003
Dr Monica Sullivan	Intensive zebra mussel monitoring, snorkeling, diving, underwater video supervision, report writing and spreadsheet management	2000-2003
Dr Dan Minchin	Intensive zebra mussel monitoring, Seabed Survey supervision, navigator of research vessel	2000-2003
Seabed Surveys	Roxann^{Tm} Survey of lake substrates	2001
Monterrey Software Mr Ivor Marsh	Digitised Mapping of Roxann^{Tm} and other project data	2001-2002
Mr Martin Manning	Underwater video work for substrate mapping of the shallow areas of the lake and reed bed survey work	2001-2003
Mr Peter Walsh	Boat-handling for routine lake monitoring	2001-2003

Chapter 2. Materials and Methods

Materials and methods are divided into two sections. Section 2.1 outlines project sampling locations. Section 2.2 details the sampling and analyses procedures.

2.1 Sampling Locations

This section outlines the Lough Key and Boyle River sites selected for water temperature, transparency, chlorophyll *a*, phytoplankton, phosphorus and zebra mussel sampling (larvae, juveniles and adults). The sampling schedule for each parameter and zebra mussel life stage is also included.

2.1.1 General Monitoring Programme

An extensive monitoring programme was carried out for a range of physical and biological parameters. Water temperature, transparency and chlorophyll *a* samples were taken at the four sampling sites used in the 1998 and 1999 surveys (Lucy and Sullivan, 2001). An additional site was added to the survey at the northern end of the lake from 2000 onwards (summer only), as this had been noted for the presence of high density zebra mussel populations during the 1999 survey. A monitoring programme for zebra mussel larva and settlement also took place at the above sites. Fig 2.1 shows the five Lough Key monitoring stations (Sites A-E). Weekly sampling was implemented from July to mid September. Fortnightly sampling was carried out from March to June each year and also from late September to the end of October in accordance with the scheduled sampling programme. Sampling for transparency, chlorophyll *a*, zebra mussel larvae and juveniles was also carried out in summer 2000, in the year prior to the commencement of this project.

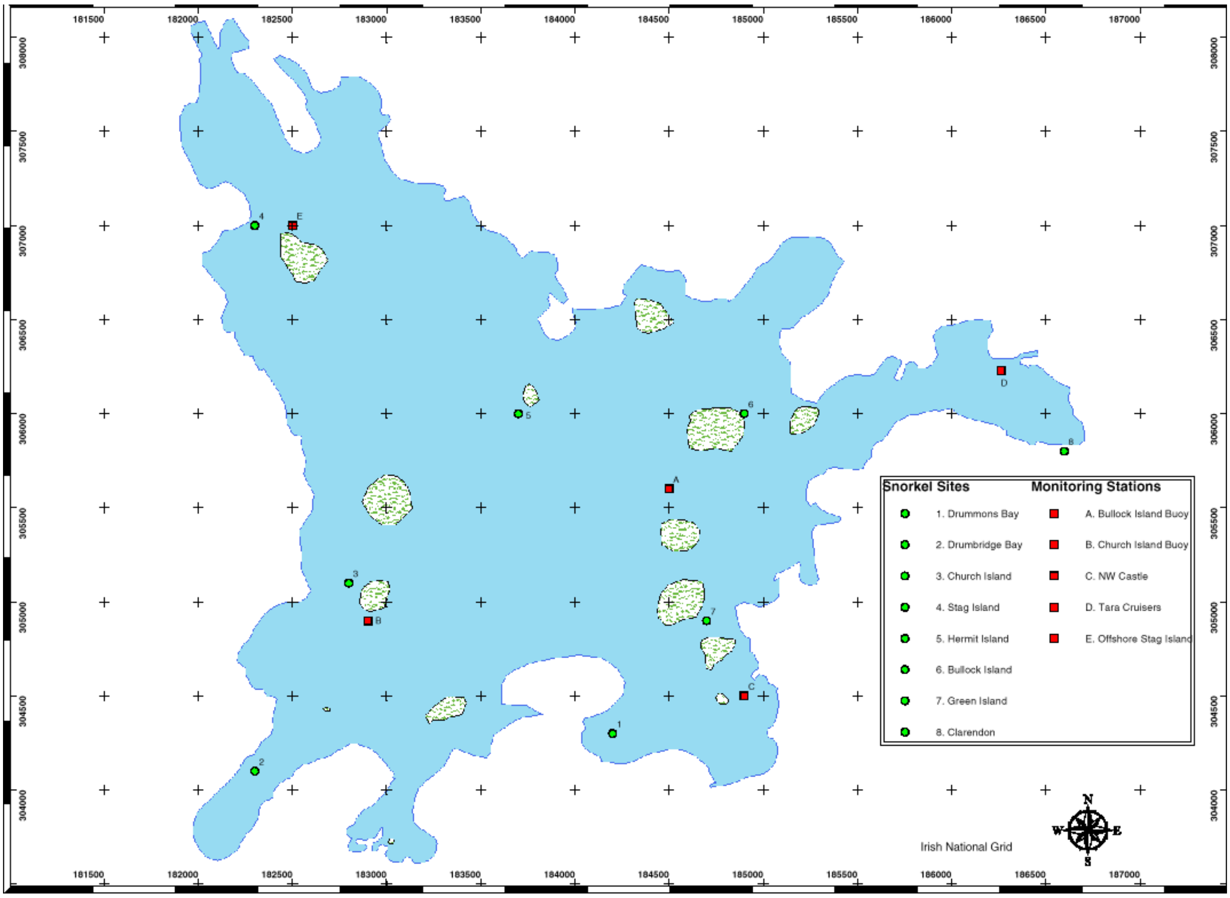


Fig. 2.1 Monitoring stations and snorkel sites, Lough Key

2.1.2 Intensive Larval Sampling

Additional stations were selected for an intensive larval sampling programme, which took place in August 2001. Twenty-three stations were selected along NW-SE and NE-SW lake transects, with an additional intensive survey of the SE corner of the lake.

2.1.3 Adult Zebra Mussel Sampling

Eight sampling stations (Sites 1-8) were selected as snorkel sites at the commencement of the project in 2000 and were resurveyed in August 2001 and 2003 (Fig 2.1). Video reed bed survey sites corresponded with these sites.

In order to assess total biomass and number of zebra mussels in the lake samples were taken along 4 transects. These transects ran from a lakeshore point across the centre of the lake to the opposite shore (Fig 2.2).

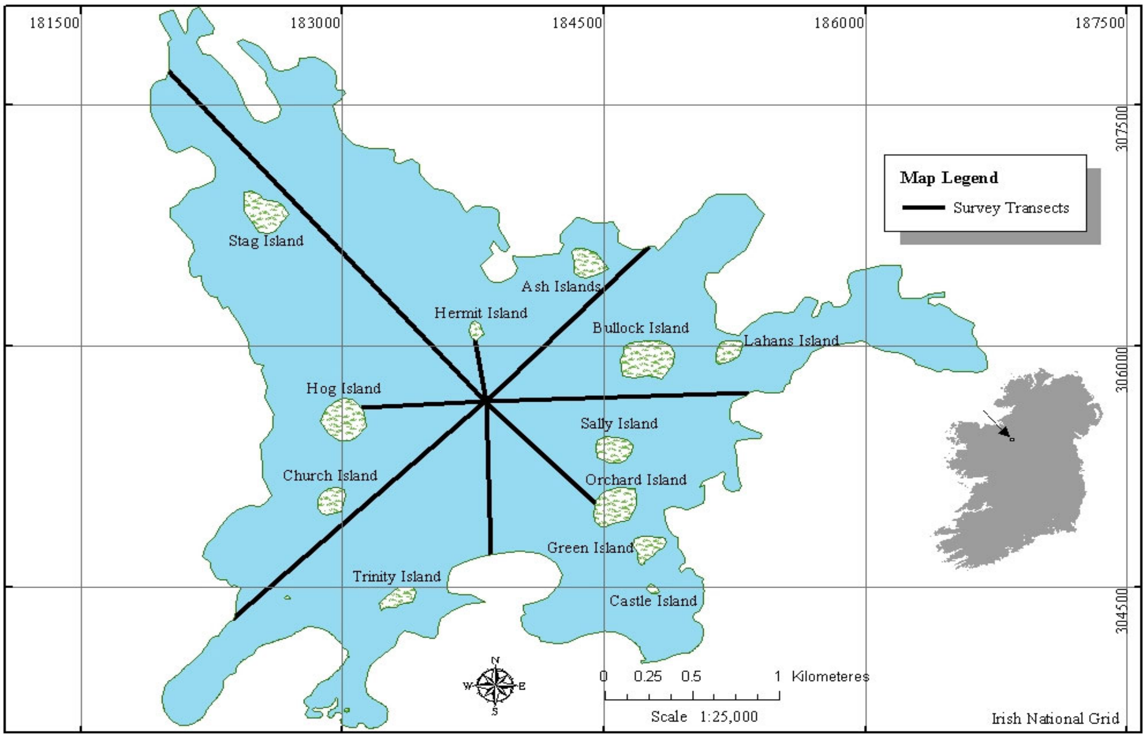


Fig. 2.2 Transects used in Lough Key zebra mussel population survey

Four standard axes were chosen in order to map the lake efficiently and avoid any bias. The transect lines were:

a) N->S
b) E->W
c) NE->SW
d) NW->SE

2.1.4 Phytoplankton Sampling

Phytoplankton samples were taken by the EPA at sampling Station C (G 835 053) during the following periods: March 2000, 2002 and 2003; April 2001; July 2000-2003; September and October of 2000, 2001 and 2003. The datasets produced were used in this project.

2.1.5 Phosphorus Sampling

- EPA data for the report is from the five Lough Key stations (A-E) used in annual surveys as selected by Toner (1979). The sampling schedule was the same as for phytoplankton sampling. An additional sample was analysed in November 2002.

- Roscommon County Council (RCC) monitoring focused on the effluent discharge point at Boyle Sewage Treatment Plant (Boyle STP).
- Boyle River data (RCC/ Lough Ree-Lough Derg Survey) were from two stations on the Boyle River. One was located 0.5 km upstream (approx.) of Boyle STP at Boyle Abbey (G807 027) and the other was 1.1 km (approx.) downstream of the plant at Drum Bridge (G817 040). These sites were sampled on a monthly basis.

2.2 Sampling and Analysis Procedure

2.2.1 Transparency and Chlorophyll *a*

Transparency determination: A standard 25 cm black and white secchi disc was used to measure transparency.

Chlorophyll *a* determination: Two-litre water samples were removed from just below the water surface at each of the six sampling sites on each sampling date, during the course of the field study. Replicate one-litre samples for each site were filtered through GF 50 glass fibre filter papers within 3 hours of sampling, placed in individual bags, labelled and frozen. Subsequent laboratory analysis was carried out regularly on sample batches included defrosting, followed by immediate chlorophyll *a* analysis according to standard EPA procedures.

2.2.2 Temperature

A temperature datalogger (Vemco minilog V3.04) was deployed at Tara Cruisers (Site D) to record temperatures every four hours over the entire sampling programme. Temperature was also recorded with an alcohol-in-glass thermometer at both Bullock Island Buoy (Site A) and Tara Cruisers (Site D) during the course of the survey. A vertical temperature profile was also taken at the Hog Island deep sampling station on 8 August, 2001, to examine whether there was any thermal stratification present.

2.2.3 Nutrients

Total phosphorus (TP) as well as orthophosphate (MRP) were analysed in the EPA laboratory, Dublin and in the RCC laboratory, Roscommon using standard methods. Results were collated and relevant parameters were reviewed for the project.

The Boyle Sewage Treatment Plant (STP) flow and total phosphorus data was used to determine total annual phosphorus loadings (tonnes TP/year) to Lough Key. TP (total phosphate) loadings/m^2 to Lough Key were calculated by dividing the annual Boyle STP loadings by the surface area of the lake.

The trophic status of a lake can be predicted using the relationship between mean depth, annual phosphorus loading (g P/m^2/yr) and hydraulic retention time (τ_ω/year) (Vollenweider, 1975). This relationship was calculated for Lough Key in 1975 and 1976 (Toner, 1979) and was also used for this research to predict whether total phosphorus loadings should result in an oligotrophic or mesotrophic status in Lough Key during each year of the zebra mussel survey. Total phosphorus loads P/m^2/yr were estimated by multiplying the annual P load/g/yr by the total lake area (9,000m^2).

2.2.4 Phytoplankton and Cyanobacteria

All samples were fixed in Lugol's solution and transported to the EPA laboratory, Dublin. A qualitative examination of the phytoplankton and cyanobacteria in each sample was carried out using an inverted microscope. Taxa were identified and an indication of relative abundance recorded.

2.2.5 Zebra Mussel Life Stage Sampling

Sampling of early zebra mussel life stages (larvae/veligers and settled juveniles) has been largely adapted from a monitoring programme designed by Marsden (1992). The adult zebra mussel sampling programme was devised by the research team. The transect survey methodology was adapted from Karatayev *et al.,* (1990).

2.2.5.1 Larval/Veliger Sampling and Analysis

(a) General Monitoring Programme

Vertical tows were carried out at the five monitoring sites (A-E). A 64 µm mesh plankton net with a 30 cm diameter opening was used for veliger sampling, allowing collection of all veligers > 65 µm.

(b) Intensive Survey Work

A more detailed sampling system was utilised during the intensive larval survey work, on 10 August 2001. 50L of lake water was pumped from a depth of approx 1.5m and sieved through a net held in a 50L container (Plate 1).

Plate 1. Pump sampling of zebra mussel veligers

Vertical distribution of larvae was assessed at one station at the Hog Island Deep, near the center of the lake, at varying intervals from depths of 0.1m to 22.0m.

Fifty-litre samples were pumped from 1meter depth (approx) at varying points across the lake for larval transects. Larval distribution was also assessed by the same method on a smaller scale, by sampling the plankton in the Rockingham Bay area.

(c) Estimation of Larval/Veliger Density and Size Distribution

For the monitoring programme each sample was examined under high magnification (80-100x) microscope using one ml sub-samples in a Sedwick-Rafter Counting cell. Three one ml sub-samples were counted and the veliger density per ml of concentrated sample calculated from the mean as below:

$$\frac{\text{Number of veligers/ml x } 25^{a}}{\text{Volume of Sample}^{b}}$$

a = Volume in 25ml tube

b = 3 x 3.14 x $(0.3)^2$ = length of tow x π x radius of net mouth^2 = 848 l.

The microscope was fitted with an optical micrometer and size distributions of samples from Sites B, C and E were measured to the nearest 10μm. For the intensive larval survey, veliger density was calculated by counting the number of veligers in each 50L sample and then converting to density per litre. Student's t- tests and ANOVA tests (Statistical package, SPSS 11) were used in the interpretation of results.

2.2.5.2 Settled Juvenile Sampling

Settled juveniles were sampled using 15cm^2 grey PVC plates with three plates deployed in series at each site as in Lucy and Sullivan (2001). The rope was tied at the top to a navigational buoy at Sites A, B, C and E and held in position from a jetty at Site D. The settlement plates were suspended from a concrete anchor weight, which held the plates firmly in mid-water (3m depth approx). All plates were conditioned for one week to allow a biofilm to build up, thus encouraging settlement. The top plate at each site remained unchanged and was removed twice during the 2001 season (21 July and 21 Oct) and once during the 2002 and 2003 seasons to estimate total seasonal settlement of juvenile zebra mussels. In 2002 a second set of plates was attached at 4m depth (Site A only) to determine whether settlement would be different at this depth. On each sampling date, beginning early/mid June either the bottom or the middle plate was changed on a two-week rotation. Once recovered, the plates were placed in a sectioned sample container and then examined using a microscope for the presence of newly settled juveniles. The mean of thirty 1 x 1 cm^2 quadrats was obtained for each plate and an estimated density (m^2) was calculated.

In 2001 overall settling density (m^2 per site) for the season was estimated by adding the means of July and October top plates, to combine the original and replacement plate data. In other years the top plate count was estimated using the same method as for the two-week plates. Seasonal plate counts were compared with the cumulative two-weekly plate counts, which also provided a seasonal settlement density estimate for each monitoring site.

2.2.5.3 Adult Sampling

Adult sampling was undertaken as part of snorkel surveys, prior to and during the project (August 2000, 2001 and 2003), during the course of the transect survey (2002) or as part of ongoing monitoring.

(a) Snorkel Surveys

In 2000, 2001 and 2003 eight sampling stations were surveyed by snorkelling (Figure 2.1) to examine the biomass and size distributions of each zebra mussel population. Substrates examined included stoney substrate, *Anodonta* shell, *Phragmites australis* (old and new), *Schoenoplectus lacustris* and other plants where present.

- **Stoney Substrates**

  Stoney substrates were sampled at seven of the snorkel sites. Drummons Island (Site 1) did not have any stone present and therefore was excluded from this sampling programme. Data for 1999 and 2000 were based on weighing, counting and measuring the zebra mussels in multiple 2 x 2 cm^2 quadrats. From 2001 a new improved method was used to assess zebra mussel biomass. Stones were placed in a 25 x 25 cm^2 quadrat. The biomass of zebra mussels was removed from the stones and weighed. Overall estimates of the surface area of stones in lake sites (as a percentage of substrate) were assessed from videotape work, snorkeling and scuba diving. The percentage of zebra mussel cover on stoney substrate was also assessed using these methods. Size distributions were taken for >150 zebra mussels per sample. Firm substrates were also targeted for the detection of zebra mussels at varying depths using a Van Veen grab.

- **Zebra Mussels on Reeds, Rushes and other Aquatic Plants**

  Ten old and ten new common reeds, *Phragmites australis,* were cut at their base from outer fringes of reed bed sites. Ten common rushes, *Schoenoplectus* *lacustris* were removed in the same way. Zebra mussel biomass and size distributions on these plants were compared. A qualitative assessment was also undertaken on submerged and marginal plants including water lily, *Nuphar lutea* and horsetail, *Equisetum fluviatile*.

- **Zebra Mussels on *Anodonta***

  Thirty paired *Anodonta* shells were removed from each snorkel site. The length and weight of the *Anodonta* shell, weight of zebra mussel fouling and estimated age of *Anodonta* were measured. The numbers of *Anodonta* per m^2 and other qualitative information (qualitative) were also assessed on all videotapes and during snorkel and dive surveys.

Datasets were collated and analysed for this report. Size distribution and biomass results were compared statistically using t-tests, G tests, ANOVA and post-hoc Tukey HSD test ($p<0.05$) where data were normal and variances were homogenous (Levene statistic, $p>0.05$). When data were not normally distributed and the variances were heterogeneous (Levene statistic, $p<0.05$), Kruskal-Wallis and post-hoc Mann-Whitney test-tests ($p<0.05$) were applied. The statistical package SPSS 11 was used to carry out the various statistical analyses (Howit and Cramer, 2003).

(b) Transect Survey- Sampling Density and Biomass of Adult Zebra Mussels

Samples were taken along eight transects in order to study the density and biomass of adult zebra mussels in the lake. In order to acquire good, complete datasets, two methods of sampling analyses were used, namely grab sampling and scuba diving. A quadrat frame size 25 x 25 cm (sampling $0.0625m^2$), was used for sample collection by scuba diving. Since it was not feasible to dive the complete transects until they met in the centre, a Van Veen grab was also used ($1/40\ m^2$, i.e. $0.025m^2$). At each site/depth interval, a replicate of 3 samples was collected. Maximum lake depth along each transect was also recorded (Table 2.1).

Table 2.1 Sample method and maximum depth for project transects

Transect	Dive (m)	Grab (m)	Max Depth (m)
North	0-6	3-7.6	7.6
South	0-5	4-18.7	18.7
East	0-4	4-11.5	11.5
West	0-4	4-19.3	19.3
Northeast	0-4	3-8.3	8.3
Southwest	0-4	4-19.1	19.1
Northwest	0-4	4-14.8	14.8
Southeast	0-6	4-20.0	20.0

Latitude and longitude co-ordinates were taken at all grab sampling stations, but it did not prove possible to take GPS readings at dive locations, since the boat was moored off-site (due to hazardous rocky substrates in shallow waters) and the diver collected samples from random, discrete locations underwater. The diver did however follow a strict bearing along a specific transect line at all times. Mussels were collected by the diver at depths of 1.0 metre intervals from the shoreline to a depth of 6 metres. The substrate category generally dictated the method of sampling required, i.e. once the substrate was predominantly transitional or mud (categories 2 or 1 respectively: see section 3.2.1), it was deemed appropriate and feasible to sample by grab analyses.

A small pilot sampling programme of the effectiveness of grab sampling versus scuba diving sampling was carried out where the sediment categories moved towards transition and mud, i.e. 3 and 4m. The southeast transect was chosen for this study at a depth interval of 4 – 5 metres. Dive samples (surface substrate including plant material) were placed directly into collection bags, taken to the surface and analysed immediately. Grab samples were placed in a sieve and rinsed over a basin. A representative sample population from each substrate, at each depth, was kept frozen for size population dynamics analyses later.

Determination of the density and biomass of zebra mussels

The average density and biomass of zebra mussels in Lough Key were calculated by following four statistical steps as below:

Firstly, the mean density and biomass for each of the eight transects was calculated as follows:

1. From the datasets collected, the mean density/biomass of the mussels per each depth interval (0-1, 1-2, 2-3m, etc.) was recorded as the average for all samples taken from these depths, i.e. average density/biomass of samples taken from 1 to 2 metres gives the mean for a 1-2 metre depth interval. e.g.

$D_{1\text{-}2m}$=$D_{1.0m}$ +$D_{2.0m}$ / No. of samples

where $D_{1\text{-}2m}$ = mean density on the depth interval (1-2) of the transect

$D_{1.0m}$ = average density from samples taken on 1.0 metres depth of the transect

$D_{2.0m}$ = average density from samples taken at 2.0 m depth of the transect.

2. This mean density/biomass for each depth is then multiplied by the area of that depth interval (for example, if 0-1 m depth interval in the lake occupies an area equal to 0.5 km^2 and 7-8 m occupies 0.3 km^2 etc. then we have to multiply, for 0-1 m by 0.5 etc.). These areas were all calculated from Seabed Surveys Bathymetric charts created for the lake.

$D_{0\text{-}1m}$ * $A_{0\text{-}1m}$

where $D_{0\text{-}1m}$ = mean density on the depth interval (0-1) of the transect

$A_{0\text{-}1m}$ = area under the depth interval 0-1 metres in the lake.

3. All the mean values for each depth interval taken from each site along the transects (0-1, 1-2, …….19-20m) are then added and this sum divided by the total area of the lake bottom (again obtained from Seabed Surveys Anaylses)

$$D_i\,section = \sum_{j=0,\,n=1}^{N} D_{j\text{-}n} \text{ x } A_{j\text{-}n} \,/\, A_{\text{lake}}$$

where D_i *section* = mean density of the i section

$D_{j\text{-}n}$ = mean density on the depth interval *j-n* (metres) of the section

$A_{j\text{-}n}$ = area under the depth interval *j-n* in the lake

A_{lake} = total area of the lake j, n = starting and ending depth of (j, n) interval where *j=0* N-1, *n=1*

N =maximal depths at which zebra mussels occur in Lough Key.

All mean values for each sampled section (equal to the number of sections sampled) are now calculated.

4. The average (+/- SD or SE) density and biomass of zebra mussels in Lough Key was then calculated using the mean values for each section as follows:

$$D_{lake} = \varepsilon_{i=1}^{M} D_i$$

where D_{lake} = average density of zebra mussels in the lake

D_i = average density of zebra mussels at the *i* section

M = number of sections sampled in the lake

(c) Ongoing Monitoring

Adults were also sampled periodically during the three-year project from a jetty due east of Drummons Bay (Site 1). These were scraped from the vertical surface of the Rockingham jetty (G 845 043) using a scraper attached to a 3m pole (Minchin *et al.*, 2002). A size distribution and biomass were taken for each sample.

(d) Reedbed Video Survey Work

Four reedbeds at different locations within the lake were surveyed by the ROV (remotely operated vehicle) camera once per season, between summer 2001 and 2003. Methodology for the ROV is included in Section 3.3.1. The videotapes were analysed to assess presence and possible seasonal movement of zebra mussels on these plants during different seasons over the course of the project. Footage of zebra mussels on other substrates was also undertaken when the 'photo opportunity' arose.

2.2.6 Estimation of Filtration Capacity of Zebra Mussel Populations in Lough Key

The transect survey provided the wet biomass of zebra mussels in the lake. A filtering rate of 44.4 ml/g WTM^{-1} h^{-1} (Wet Tissue Mass) was obtained by taking the mean of five independent East European surveys carried out at similar summer temperatures (Kondratiev, 1962; Stanczykowska, 1968; Lvova, 1977; Karatayev and Burlakova, 1993; Karatayev and Burlakova, 1995). The product of the biomass and the filtering rate was multiplied by 24 (hours) to give the daily filtration capacity of the zebra mussels in Lough Key. The lake volume (46 x 10^6 m^3) was divided by the filtration capacity to estimate how quickly the population could filter the entire lake during the summer period.

2.2.7 Roxann^{Tm} Survey, Computer Analysis, Groundtruthing and Video Surveys

Methodology for this survey is included in Chapter 3.

2.2.8 Photographs

A library of relevant survey photographs was filed during the course of the project. These included photographs of research work and zebra mussel fouled substrates.

Chapter 3. Development of Lough Key Sediment and Depth Models with Subsequent Ground-truthing, Video Survey Work and the Development of a Habitat Map

This chapter details the development of the lake sediment and depth model followed by a ground-truthing survey. Research results were combined with a subsequent video survey and transect work to develop a habitat map for Lough Key.

3.1 Development of Sediment and Depth Models for Lough Key Using Data Generated by an Acoustic Ground Discrimination System (Report by Seabed Surveys Ltd and Monterrey Software)

3.1.1 Background

The RoxAnn™ acoustic ground discrimination system (AGDS) was used to collect bathymetric and sediment data in Lough Key. This system allows the collection of large volumes of data, which are achieved remotely, with the result that there is no disturbance to the lakebed by the act of observation. The post-processed hydro-acoustic data from the survey of Lough Key was integrated with Geographical Information System (GIS) Technology, which was employed by Monterrey Software to develop sediment and depth models of the surveyed lake. These models can then be used to extract baseline data for use in scientific and spatial analysis. There is potential to combine information from dive and grab-sampling programmes with the sediment and depth models in order to investigate the relationship between sediment and depth on the distribution and abundance of zebra mussels within Lough Key.

3.1.2 Hydro-acoustic Survey

Prior to the survey of Lough Key, survey tracks were designed, using Microplot electronic charting software, which enabled the survey vessel to follow a pre-determined route. A systematic parallel survey design was implemented and transects were run in an East-West direction. Transects were set at two levels of intensity, using near shore transects spaced at 50 metres and offshore transects spaced at 100 metres, in order to concentrate the sampling effort in shallow parts of the lake where highest zebra mussel densities were expected. The cruise track employed during the course of the survey is illustrated in Figure 3.1. Where sufficient depth allowed, the vessel followed this pre-determined track throughout the survey.

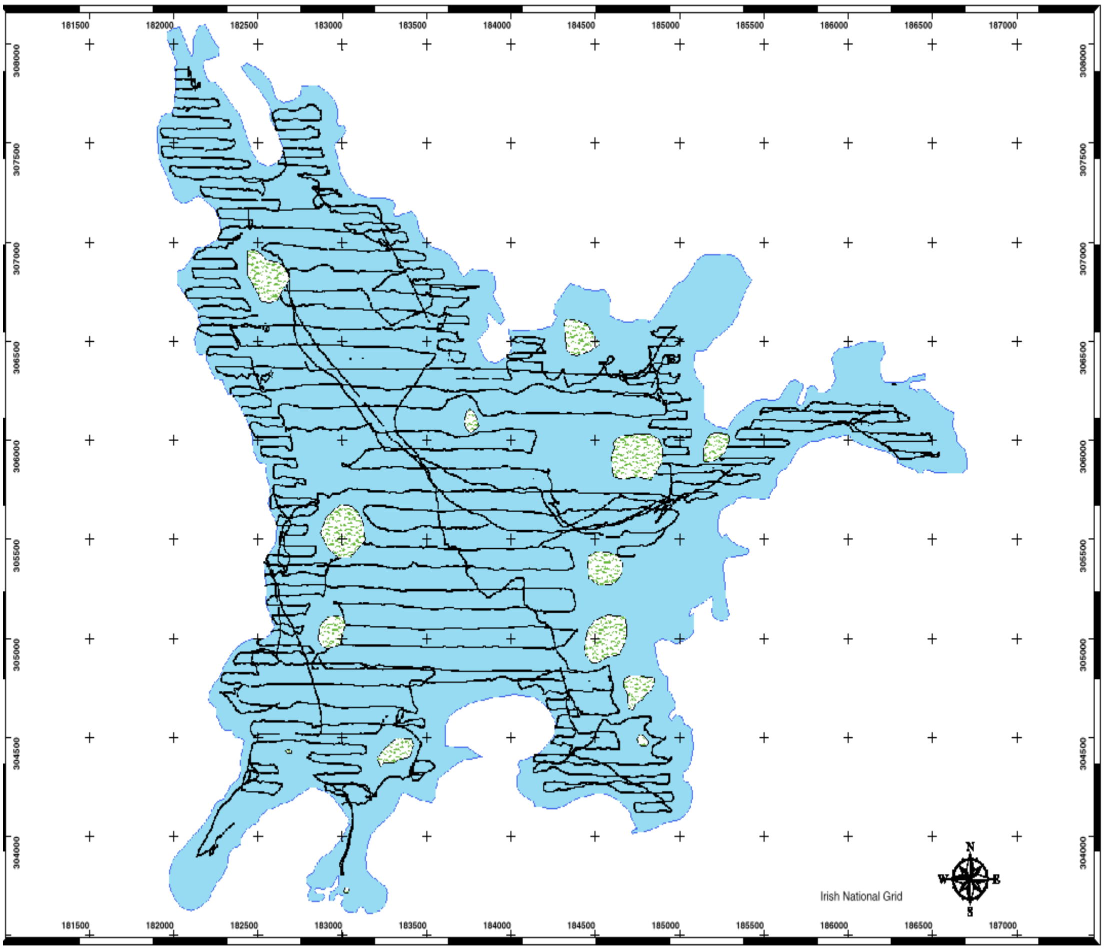


Fig. 3.1 The Lough Key Roxann ™ survey track, Seabed Surveys Ltd.

The survey was carried out on board a 17ft cabin cruiser between the 26 May and the 5 June, 2001. The vessel was equipped with an inverter and batteries in order to produce a clean consistent power supply to allow the collection of acoustic data with minimal noise and interference. The transducer was mounted on a pole attached to the starboard side of the vessel, in order to minimise any signal attenuation due to aeration. A 200 kHz RoxAnn™ acoustic ground discrimination system (AGDS) was used for the collection of sediment type data. Positional accuracy was maintained throughout the survey using Koden Differential Global Positioning Systems (DGPS) set to output the WGS84 Datum.

3.1.3 Description of the Acoustic Ground Discrimination System

The RoxAnn™ hydro-acoustic processor was used to provide detailed discrimination between lakebed sediment types. RoxAnn™ operates as a passive receiver of acoustic signals generated by a standard single beam echo sounder. Using two digital indices generated from the first (E1) and second echoes (E2) observed via a dedicated parallel receiver, ground discrimination can be successfully achieved. E1 is an integration of the tail of the first echo, and provides an estimation of the evenness or roughness of the sediment, whilst E2 is an integration of the whole of the second echo and indicates the hardness of the substratum. Changes in E1 and E2 occur because different lakebed material types reflect sound from the transducer in different ways. These differences are reflected in the strength of the voltages of the returned echoes. Using the E1 and E2 values in combination allows the operator to identify the nature of the lakebed and to distinguish a wide range of sediment types ranging from, fine mud through sand and gravel, onto cobbles and bedrock.

3.1.4 Ground-truthing

Prior to the collection of data the equipment was calibrated over a variety of sediment types in order to allow the creation of a "boxfile" based on an E1 versus E2 scatterplot. Various "box sets" can be applied to the data so that each box has a minimum and maximum E1 and E2, which relates to the acoustic signature produced by a particular sediment type. A 0.25 m^2 Van–Veen grab sampler and an underwater camera mounted on a drop frame were used to provide the ground-truthing information for the AGDS system.

The data was edited in real-time for the selection of appropriate ground-truthing sites by re-analysing the data to detect 'natural' clusters in E1 and E2 values. Once these clusters have been identified a grab or camera is employed to identify the sediment type that produces this acoustic response. Real-time visualisation using Microplot allows the operators to keep a constant check on variations in bottom type, consistency between tracks and sediment discrimination (with regard to *in situ* observations using the grab or camera).

3.1.5 Preliminary Data Treatment

Depth spikes were removed from the dataset using a Median programme designed to remove obvious outliers from the data-set prior to mapping. In certain deeper parts of the lake it was difficult to obtain satisfactory depth measurements due to sub-bottom penetration of the sound pulse in very soft sediments. When this occurs there is a fundamental confusion between lakebed backscatter and sub-bottom reflection because they arrive back at the transducer at the same time. This problem is not specific to RoxAnn™ and will be shared by any acoustic system, which attempts to classify the lakebed, by the analysis of echosounder signals. Sound energy can penetrate the sub-bottom if the echo sounder is using low frequencies, high power or operating in very shallow water, and it is more likely to occur in soft substrates. In order to collect correct depth measurements it was necessary to re-survey these areas using a different hardware setting, which allowed the collection depth recordings over very soft substrates.

3.1.6 Mapping and Modelling of Acoustic Data

On completion of the survey, all ground-truthing sites were overlain onto the track data for the purpose of fine tuning the "boxfiles". New "boxfiles" were then created based on both ground-truth data and E1 and E2 clusters. Any clusters that were not backed up by the ground-truth data were included as unknowns. A numerical value relating to sediment or plant type was assigned to each of the "boxfiles". Plants on the lakebed produced characteristically high E1 values and were easily identified from bare sediment.

Logistically, it is not always possible to get exhaustive values of data at every desired point. Therefore, interpolation is important and fundamental to the generation of geo-statistical models. Kriging is a geo-statistical interpolation method that provides a means of interpolating values for points not physically sampled, by using knowledge about the underlying spatial relationships in the dataset. Kriging is based on regionalised variable theory and is superior to other means of interpolation because it provides an optimal interpolation estimate for a given coordinate location, as well as a variance estimate for the interpolation value. The kriging method uses a variogram to express the spatial variation and to minimise the error of predicted values. Ordinary kriging was the interpolation used to determine depth. The bathymetric chart is illustrated in Figure 3.2. It was possible to zoom in to any specific lake area using the electronic version of this map. Table 3.1 gives the estimated area (m^2) at different depth zones within Lough Key. The RoxAnn™ survey could only research lake areas >2m in depth. The total lake area <2m deep was extrapolated using the relevant Ordnance Survey Ireland (OSI) vector tiles. Substrate mapping of areas <2m depth were carried out by the Remotely Operated Vehicle (ROV) video survey.

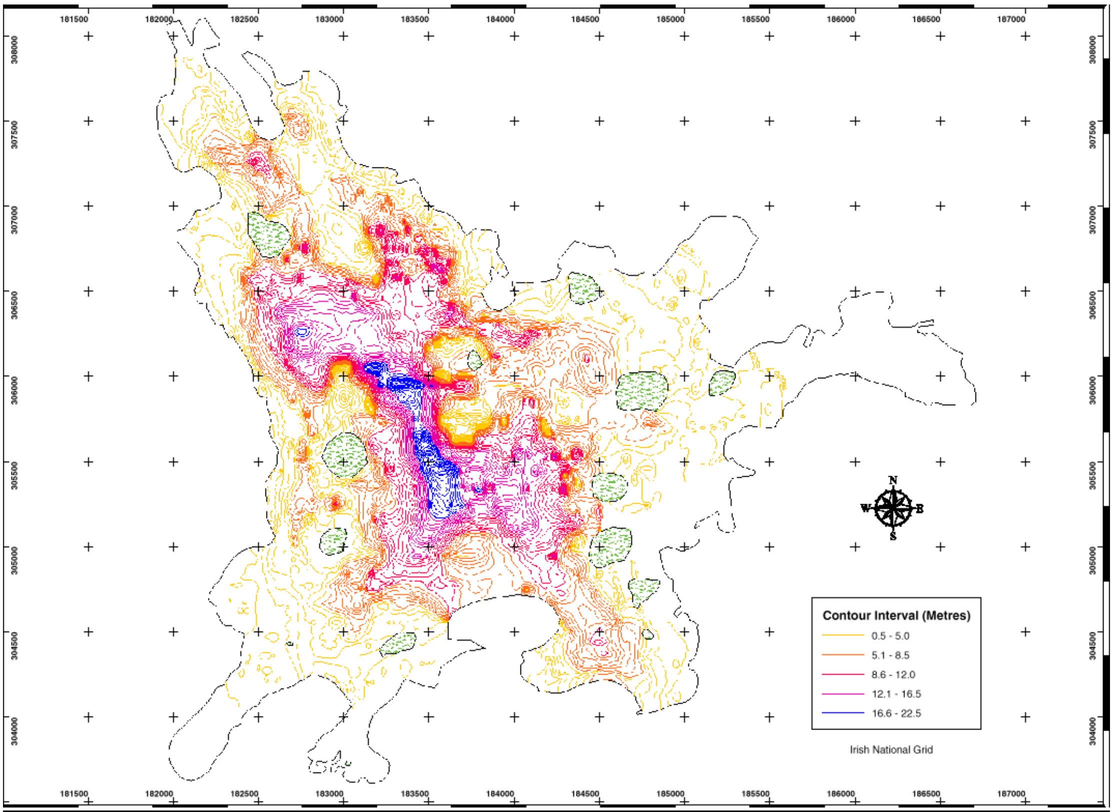


Fig. 3.2 Bathymetric chart of Lough Key, Seabed Surveys Ltd.

The mean depth of the lake is estimated at 4.5m, slightly less than the 5m result in Toner (1979) and 50% of the lake area has a depth range of 2-5 metres.

As sediment data is categorical and depth data is continuous a different method of interpolation, i.e. nearest neighbour algorithm, was used to generate the sediment model (Figure 3.3). Sediment types obtained by ground-truthing and corresponding RoxAnn™ colour codes are presented in Table 3.2.

Table 3.1 Total area and percentage of depth zones in Lough Key, estimated by RoxAnn™

Depth Zone	Area m^2	% Lake
0-<2	673,123.7	8.0
2-<3	1,628,143.8	19.3
3-<4	1,809,059.39	21.5
4-<5	849,639.33	10.1
5-<6	506,684.03	6.0
6-<10	1,663,773.69	19.8
10-<14	805,489.69	9.6
14-<18	355,156.93	4.2
18-20	61,619.00	0.7
18-<22	46,297.02	0.5
>22	25,085.6	0.3

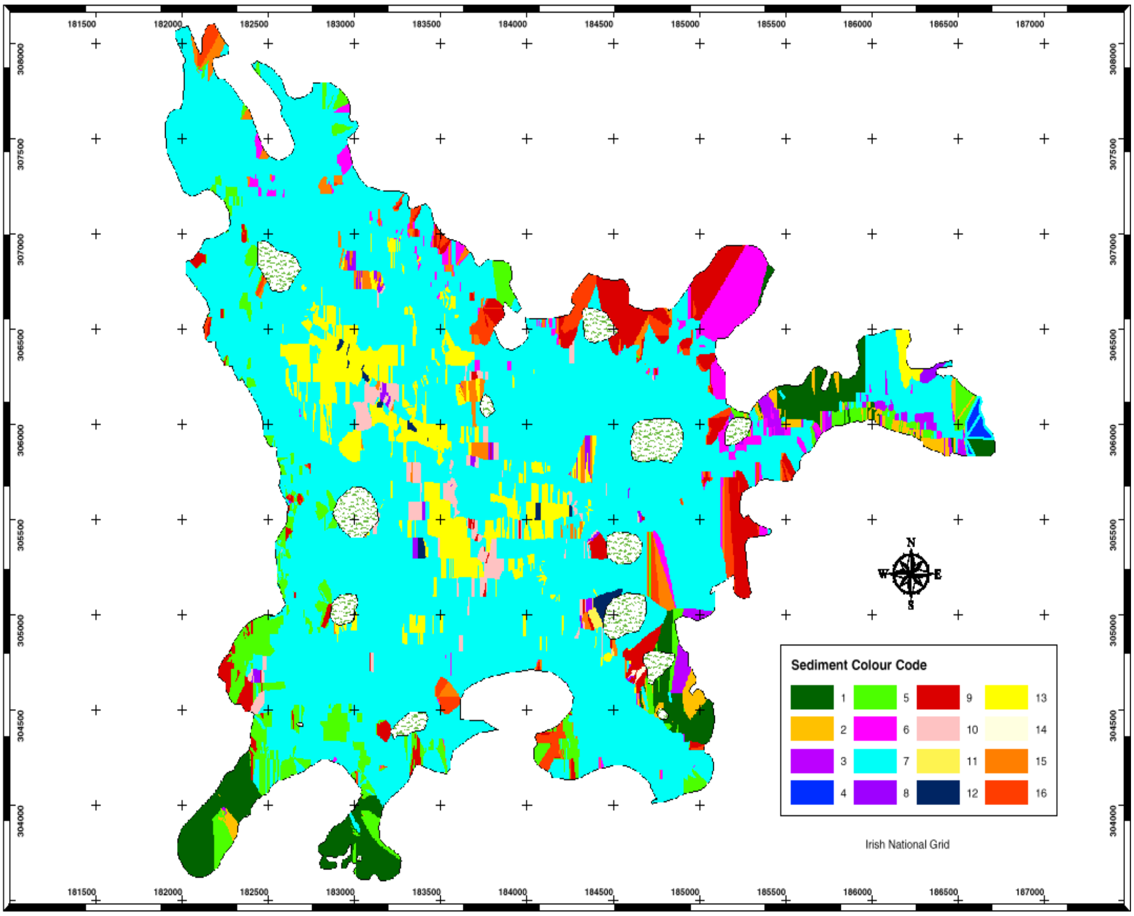


Fig. 3.3 Lough Key sediment types classified by RoxAnn™, Seabed Surveys, Ltd.

Table 3.2 RoxAnn™ Colour Codes and sediment descriptions for the Lough Key Sediment Model

Colour Code	Colour	Sediment Type	Observations
1	Dark Green	Algal beds on mud	*Cladophora* (algal) beds on muddy substrate
2	Deep Yellow	Algal beds on mud	Acoustic signature is definitely different than Colour 1 Camera footage looks the same as above Possibly different proportions of plant species or different underlying substrate
3	Magenta	Algal beds on mud	Same as 5 but lower E1 values
4	Electric Blue	Transition	Transition between different substrates. No definite cluster of E21 and E2
5	Green	Plants on mud	Sometimes zebra mussels attached to plant shoots Also found zebra mussels attached to small stones or dead Anodonta shells. These small stones were too small to generate an acoustic signature RoxAnn™ picked up a definite acoustic signature for plants over mud as opposed to mud
6	Pink	Sandy mud / Mud & Clay	Higher E2 values indicate harder substrate than mud alone
7	Cyan	Mud	Characteristic low E1 and E2 values
8	Purple	Transition Sediment	A few small clusters identified
9	Red	Stones & Rock	Characteristic high E1 and E2 values
10	Neon Red	Ridge or Peaks of hard bottom may be covered with mud or silt	A definite ridge shows up in the depth profile so it is likely that there is a hard ridge present. However, the ridge may be covered with liquid mud or silt which can cause the sound energy to penetrate the sub-bottom thus producing high E1 values.
11	Yellow	Gravel & Stones	Only one small cluster identified.
12	Blue	Unknown	Looks like something very hard as the E2 value went right off the scale
1	Gold	Liquid mud/silt but E1 and E2 values are False	This cluster indicates a lost depth reading over liquid mud or silt. In these circumstances the E1 and E2 values are affected, however, ground-truthing has shown these areas to contain mud/silt. Although the E1 and E2 values are abnormal repeatability is still maintained.
14	White	Possibly Mussels over Rock	Dense clusters of zebra mussels over rock may be resulting in lower E2 values. This is difficult to ascertain as there are only small patches of rocky areas in very shallow water and the mussels appear to aggregate in discrete clumps rather than extensive mats making it difficult if the mussels are resulting in lower E2 values.
15	Orange	Gravelly sand	A few small clusters identified.
16	Crimson	Transition / Plants on Mud	This cluster is found only in small areas. One cluster present near the Light Green Cluster (10) suggesting mud and weeds.

3.2 Ground-truthing of Roxann Survey

Groundtruthing of the Roxann data was carried out by the research team. Methodology and results for this research are outlined in the sections below.

3.2.1 Ground-truthing: Methodology

An important aspect of the 2001 fieldwork was to groundtruth the RoxAnn^{Tm} substrate map to classify substrates. Specified areas were identified for groundtruthing to verify electronic datasets given by Seabed Surveys Ltd.

The research group used separate maps and data sheets for the various lake substrates, created by the RoxAnn^{Tm} survey. Maps were plotted showing target areas for particular substrate types identified by RoxAnn^{Tm}; mud, transitional, transition with possibly sandy gravel in places, gravelly sand, unknown substrates, gravel and stones, stones and rock. Latitude and longitude points were given for all target areas. Appendix 1 includes an example of a specific map for an area identified as gravel and stone substrate.

The mapping positions chosen reflected each of the main substrates deduced by Roxann^{Tm} signals and also areas with similar echoes whose substrate was not clearly defined. Some isolated signals for rock were also assessed. A GPS was used to locate these positions, which were then ground-truthed with replicate Van Veen grab samples. GPS waypoint numbers were assigned to each grab sample. In total, the substrate classes were ground-truthed at approximately fifty locations (212 grab samples) at various locations around the lake. A map was then produced showing the four main substrate types in Lough Key at 3 m contour intervals (Fig 3.4). These substrate types are mud (category 1), transitional substrate (category 2), stone, gravel, *Anodonta* shell (category 3) and rock, boulder (category 4).

3.2.2 Ground-truthing: Results and Discussion

Results of individual ground-truth waypoints are given in Appendix 1. The following is a substrate account of ground-truthing on mud (category 1), transitional substrates (category 2), rock and stone (categories 3 and 4). Waypoint listing began at waypoint 62 due to the GPS numbering system.

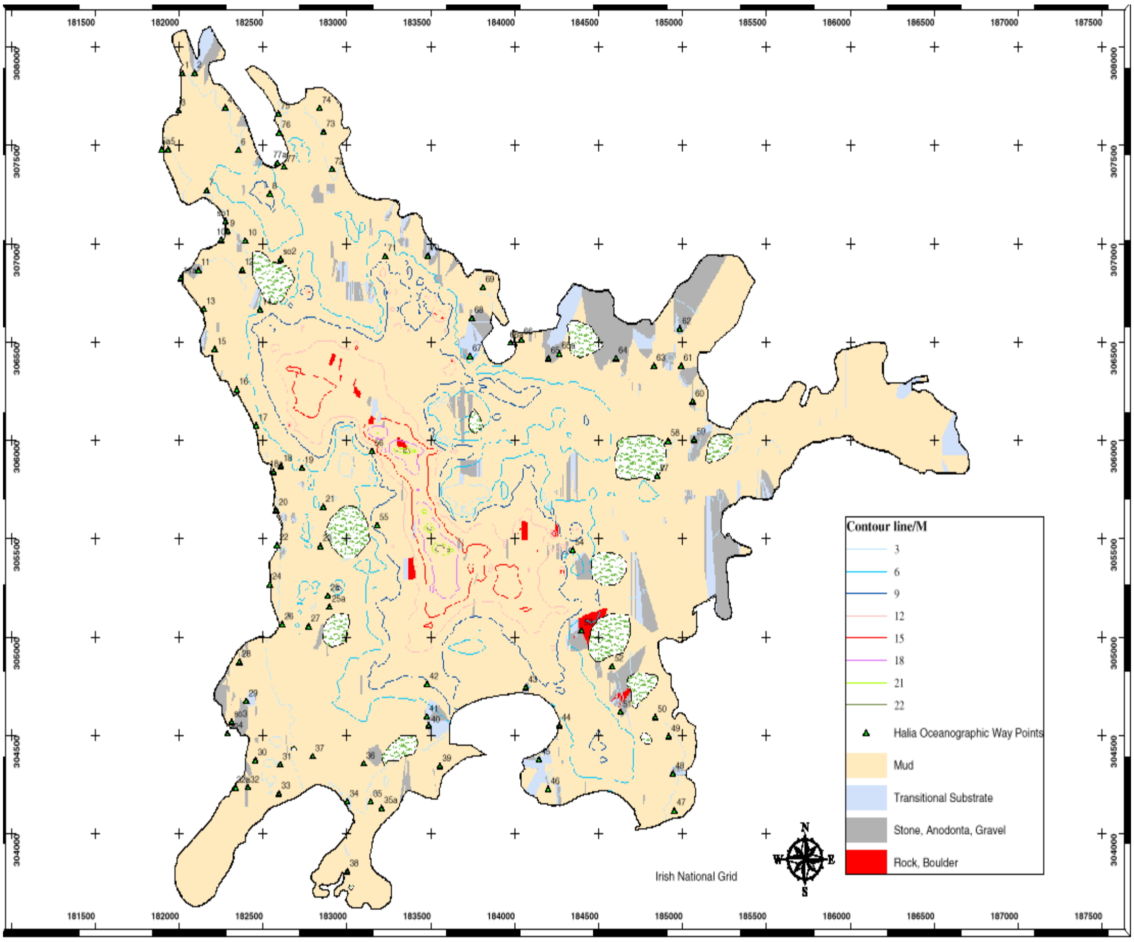


Fig. 3.4 Substrate map of Lough Key, Seabed Surveys Ltd.

3.2.2.1 Category One: Muddy Substrates

Mud was the most extensive of all the substrate types determined and therefore it was important to examine a large number of different sites at varying depths and locations within Lough Key (Appendix 1: waypoints 66-73, 203-204, 209-212). The consistency of mud substrates varied; waters deeper than 10m tended to be composed of a fine 'silky' mud with occasional fine shell fragments. Some areas, e.g. near Hog Island Deep had very fine, 'oozey' mud, devoid of any particulate matter. In other parts mud contained up to 5% approx shell content, with shells mainly buried in the mud substrate below the surface. These were mainly the shells of gastropods and in a few cases zebra mussels were found attached to shell overlaying the mud substrate. *Anodonta* shell and shell fragments were also recovered from muddy substrates (in most cases in depths < 7m). As expected from results of other survey methods, zebra mussel attachment to *Anodonta* was frequent.

In muddy shallows, submerged aquatic macrophytes, e.g. *Potamogeton, Sparganium* and the alga *Cladophora* were frequently encountered. Surface strewn gastropods and the bivalves *Pisidium* and *Anodonta* (dead shell) were common. Plant debris was frequently found to depths of 4m and below. Decaying stems of *Phragmites* were found washed-up approximately fifty metres from the perimeter of a reed bed (North Stag Island). These were colonised by two year classes of zebra mussels (0+ and 1+) with the possible consequent production of druses on an otherwise entirely muddy substrate.

3.2.2.2 Category 2:Transitional Substrates

Transitional substrates were identified at waypoints 62-64, 105-128, 167-168 (Appendix 1). Some areas identified by Roxann^{Tm} as gravelly sand were found to be predominantly mud with a small component of shell. In some cases also, small rounded pebbles were present. Adjacent to hard surfaces there were extensive areas of mud. In some cases (e.g. waypoints 167 and 168) it was evident that there was a transition zone between the two, because embedded pebbles or stones were occasionally recovered.

Small zebra mussel druses were found occasionally to a depth of 17.8m. Some of these druses had recent settlement attached. These were associated with mud.

In one small area near the Boyle River entrance (waypoints 169-172), the substrate remains unclear due to the recovery of mainly allocthonous plant debris in the grab samples.

3.2.2.3 Categories 3 and 4: Rock and Stone

Zebra mussels were found associated with stones, boulders and rock at varying depths to 17.5m (Appendix 1: Waypoints 133-135, 213-246). At greater depths it seems that such substrata may be covered with mud and silt. An apparent rocky ridge occurs adjacent to the Hog Island Deep (EPA station C) with a NW-SE alignment.

While working on hard substrates, the operator frequently felt the impact of the grab striking a hard object prior to closure of the grab. In these cases the sample could contain mats of zebra mussel druses but no actual bedrock was recovered.

Occasionally pebbles, stones or rock fragments were recovered, sometimes with attached zebra mussels and pebbles. Druses were sampled frequently indicating that this may be part of a transition zone between hard substrate and mud.

At some locations the target areas for ground-truthing were small, which lead to difficulty in maintaining the GPS position. In waypoints 142-153 sample points were thought to be outside the target area. These consisted mainly of mud with some shell.

3.2.3 Ground-truthing: Conclusions

In general, results concurred with the Roxann^{Tm} survey. The most important aspects were defining the composition of the transitional substrate and establishing the presence of occasional zebra mussels on mud and transitional substrates. Fig 3.4 maps the four main substrates found in Lough Key by the Roxann survey^{Tm}. It also includes depth contours at 3m depth intervals. The main limitations of the survey mapping depths < 2m was overcome by the video survey of shallow areas.

3.3 Video Survey Work

3.3.1 Methodology: A VideoRay remotely operated vehicle (ROV) was used to collect additional information on shallow water substrates, using inferometric methods. The video surveyed the shallow shoreline around the lake and its 13 islands, in addition to 4 specific sites over a temporal basis. The VideoRay is a highly portable ROV, manufactured by VideoRay Inc, USA.

Plate 3.1 ROV camera

The ROV system incorporates a full colour camera, with pan and tilt functions, twin variable illumination halogen lights, horizontal and vertical thrusters. The system outputs a PAL video signal, which is subsequently recorded to VHS cassette. Geographical positions of video work were maintained using a Garmin 12 XL GPS receiver in addition to a CSI ABX differential beacon receiver.

Stations were surveyed at 200m spacing around the lake, with footage recorded along transects from the shoreline to the waypoint location, in an East - West direction. A metadata report for each survey day, recorded weather conditions, station depths and a commentary of *in situ* observations were made.

The ROV was piloted over an area of substrate, initially panning from the surface down to a plan view. This allowed the viewer to obtain a view of the surrounding conditions, in addition to specific details of the benthic environment for species identification. Within the reed beds, individual reeds were surveyed at close range, from the surface to their root structure, to observe the degree of zebra mussel colonisation.

The ROV provided an effective system to record underwater environments, particularly shallow waters (less than 2 metres) within Lough Key. Stations are easily re-surveyed by returning to precise locations when using the differential GPS equipment, thus allowing a temporal and spatial study.

The videotapes were analysed and waypoints assessed according to the following criteria.

- Substrate classification: Percentage cover of rock, stone, mud, *Anodonta*, plant debris, pebbles.
- Presence of aquatic plants.
- Percentage cover of zebra mussels on *Anodonta*
- Edit suitable images for presentation

3.3.2 Results of Video Survey Work

Fig 3.4 shows waypoints used for the video survey work of lake substrates in depths of <2m. Appendix 2 gives detailed results for the substrates found at each of these points.

Substrates given can be related to the four substrate categories outlined previously. The shallow margins of the lake are often suitable for zebra mussel settlement, with 33% made up of rock, stone, pebble and *Anodonta* (Fig 3.5). Some parts of the lake perimeter were not sampled, e.g. at the eastern side (lake outlet) due to the rocky nature of the substrate (not accessible by boat) and shallow areas of the lake outlet can be considered to fit into categories 3 and 4.

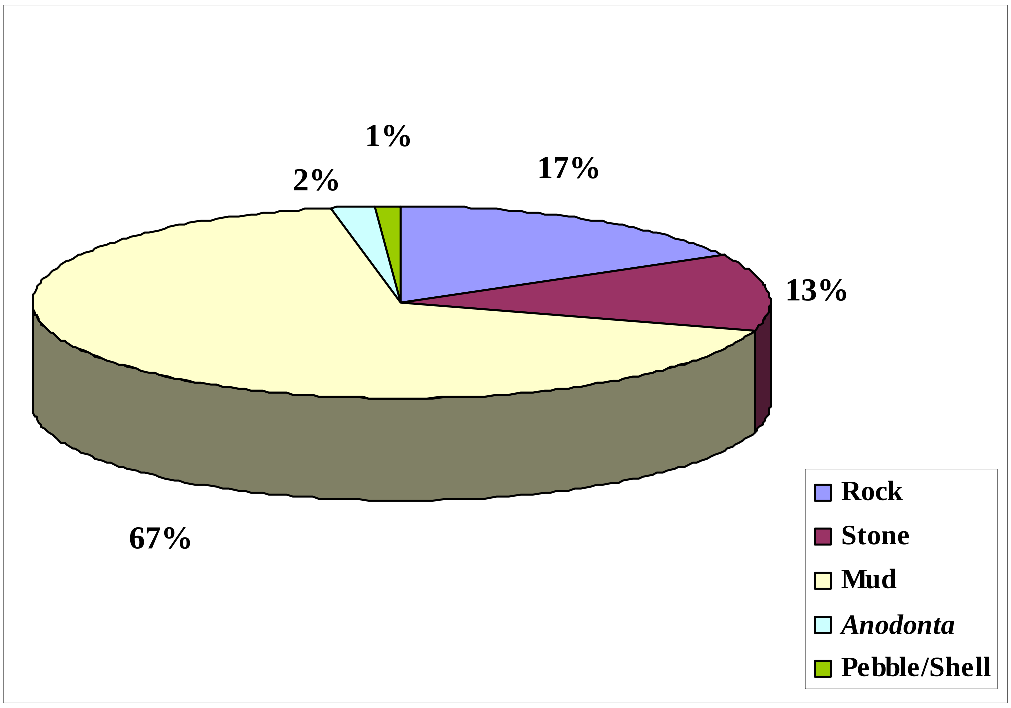


Fig 3.5 Substrate analysis of video survey

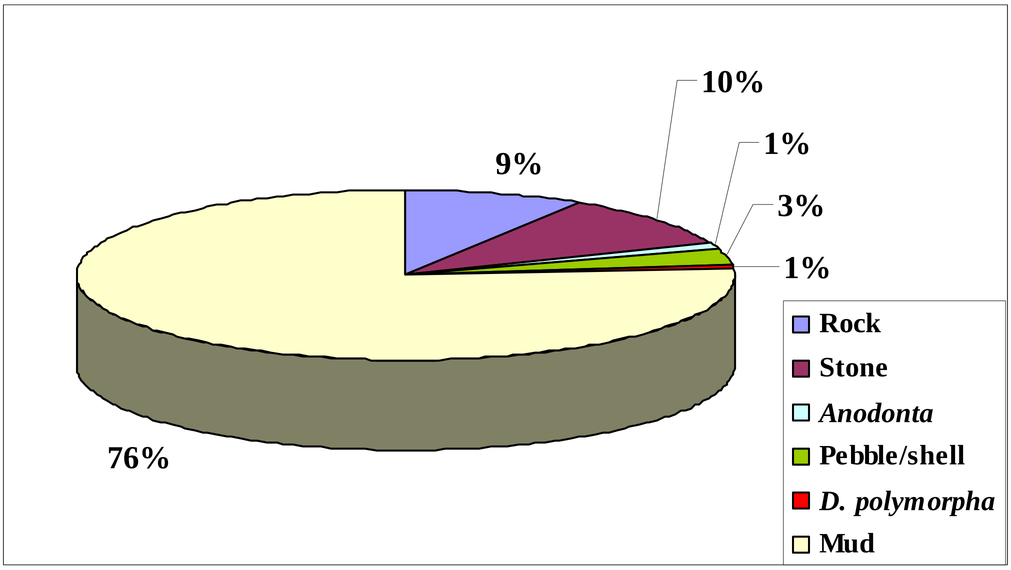


Fig 3.6 Substrate analysis of combined lake transects

3.4 Substrate Analysis of Lake Transects

In Summer 2003 it was decided to carry out a substrate survey of three lake transects to determine the proportion of different substrates from the shoreline to a five metre depth interval in each transect. As young of year zebra mussels often settle on older year classes or dead shell, the results of the transect substrate survey include zebra mussels as a substrate (1%). Other hard substrates made up 23% of the total, with 76% mud (Category 1) (Fig 3.6). Rock and stone suitable for zebra mussel colonisation dominated the first 3m of depth in each of the transects (75-95%); the proportion of these two substrates dropped however to approximately 50 % at the 3-4m range. Mud dominates from 4m depth. These results compare well with those from the video survey (Fig 3.5).

3.4 Habitat Map

Fig 3.4 can also be viewed as a habitat map, with areas marked as substrate categories 3 and 4 ideally suited to zebra mussel colonisation; category 2 and 1 as occasionally suited to zebra mussel colonisation. Shallow areas close to shorelines, mapped by video survey are generally suitable for zebra mussel colonisation as most have a percentage of rock, stone, *Anodonta* or pebble present. Colonisation of shallow areas was corroborated by snorkel and dive work for transect and snorkel site surveys during the course of the project (2001-2003) and earlier (1999-2000). This habitat map provided a baseline for some of the investigative work on zebra mussel populations in the lake during the course of the project.

Chapter 4. Results

4.1 Transparency

Zebra mussels remove a wide range of particulate matter from the water column (Hebert *et al*., 1991). In Lough Key the population began to increase rapidly in 1998 and a corresponding increased water transparency has been recorded since 1999 (Bowman, 2000; Lucy and Sullivan, 2001). Mean transparency in 1998 was 1.5m, in 1999 it had increased by 1m to 2.5m, a highly significant increase (Mann-Whitney, $P < 0.001$). Transparency continued to increase at the beginning of the project, with a value of 3.4m recorded in 2001. There was no significant increase in transparency in 2002. Water transparency was typically low during the early part of 2003 with levels increasing during June due to drier, calmer weather conditions. Although there was no significant increase in overall transparency in 2003, transparency increased over the summer season and results in late October averaged 3.8m, the highest value recorded during the project period**.** Fig 4.1 shows average transparency values from three sites (Sites A, B and C) for seven weeks from July to September in 2000, 2001 and 2003. Mean values were higher in 2001 than in the other project years, including 2002. Appendix 3 gives the complete Lough Key project transparency dataset for 2000-2003. These trends in transparency levels are also generally reflected in data collected by the EPA for these years (Appendix 4).

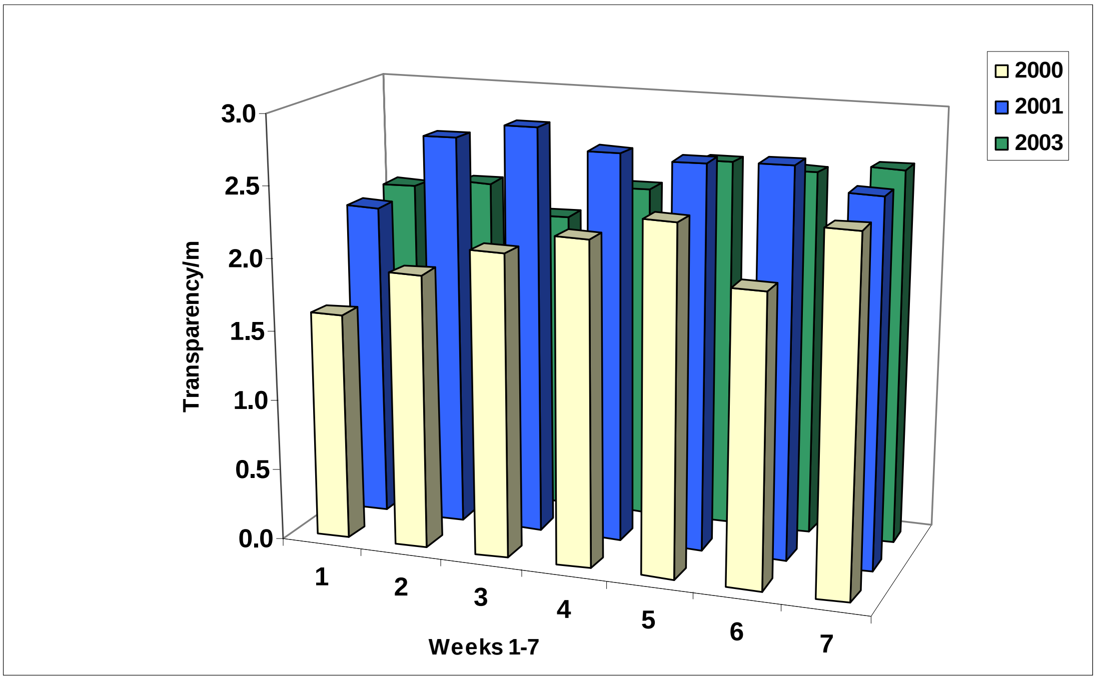


Fig 4.1 Mean transparency values/m (Sites A-C), weeks 1-7 (July-September), 2000, 2001 and 2003

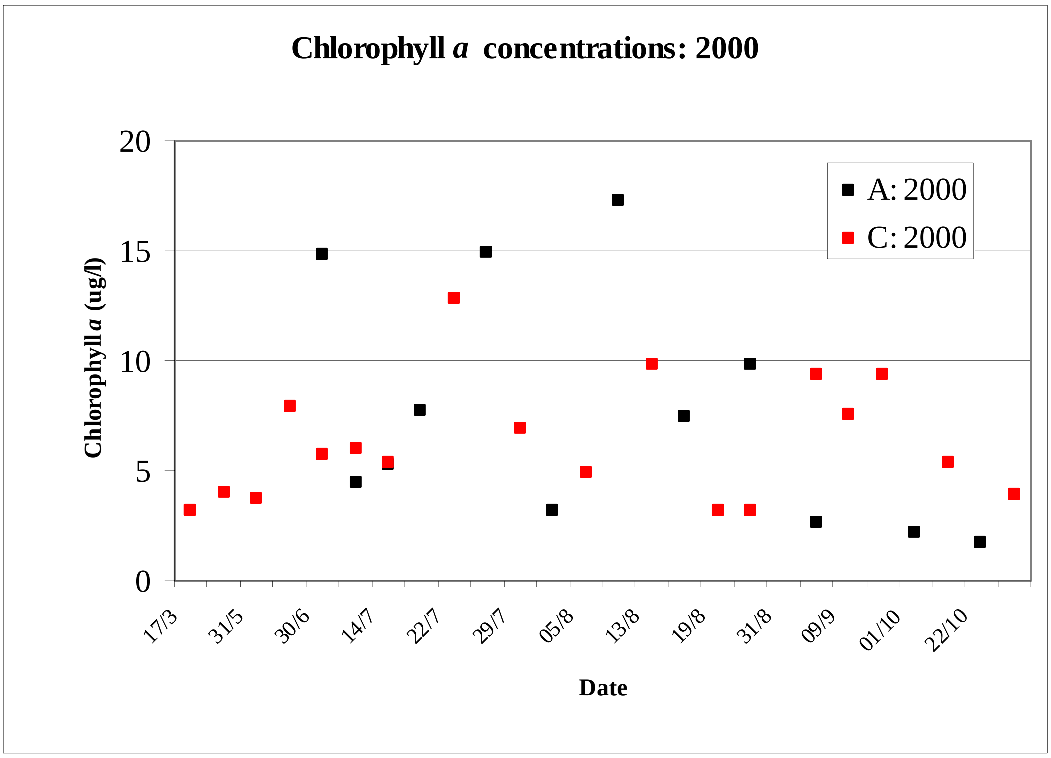
4.2 Chlorophyll *a*

The results for chlorophyll *a* are dealt with in chronological order, from 2000 to 2003. Complete chlorophyll *a* results are shown in Appendix 3.

2000 and 2001: Fig 4.2 shows trends in chlorophyll *a* concentrations at Sites A and C during 2000 and 2003. Most individual values outside the summer period fall within the oligotrophic category (<8 ug/l). In general, levels between mid June and late August 2000 and 2003 are mesotrophic (8-25 ug/l) (OECD, 1982) with elevated values corresponding with seasonal algal blooms.

2002: Chlorophyll *a* results for the sampling period were low, with a maximum level of 9.73 µg/l recorded at Site A on 8 August 2002 during a slight bloom. With the exception of two other similar results (9.24 µg/l at site A on 13 July 2002 and 9.63 µg/l at Site C on 21 July 2002) all other results during the sampling period were < 8 µg/l. These results indicate that Lough Key could almost be classified as oligotrophic during 2002 (OECD, 1982) on the basis of chlorophyll *a*, although results were not significantly lower than in 2001 (Mann-Whitney, $p > 0.05$).

2003: March/April results for Chlorophyll *a* were low as anticipated with a maximum level of 7.49 μg/l recorded at Site B on 11 April 2003. June results were higher than those obtained in 2002, with mesotrophic levels recorded on 15 June 2003 at Sites C and D (11.18 and 10.99 μg/l respectively). A level of 10.22 μg/l was recorded at Site E on 30 June 2003. Chlorophyll *a* results for the 2003 sampling period were not significantly higher overall (Mann-Whitney, $p > 0.05$) than in 2002 with a maximum level of 22.38 μg/l recorded at Site C on 22/07/03, during a slight bloom. From fifty-four samples taken over an eleven-week period (31 May 2003 – 9 September 2003), thirty-one were < 8 μg/l. These included all sites during two sampling weeks in mid/late August. As the rest of the sample results fell between 8 and 22.38 μg/l, Lough Key could be trophically classified as mesotrophic in terms of chlorophyll during 2003 (OECD, 1982). Fig 4.3 shows the chlorophyll *a* and transparency levels at Site 1 during 2003, there was no statistical correlation between these parameters ($r = 0.25$, $p = 0.32$).



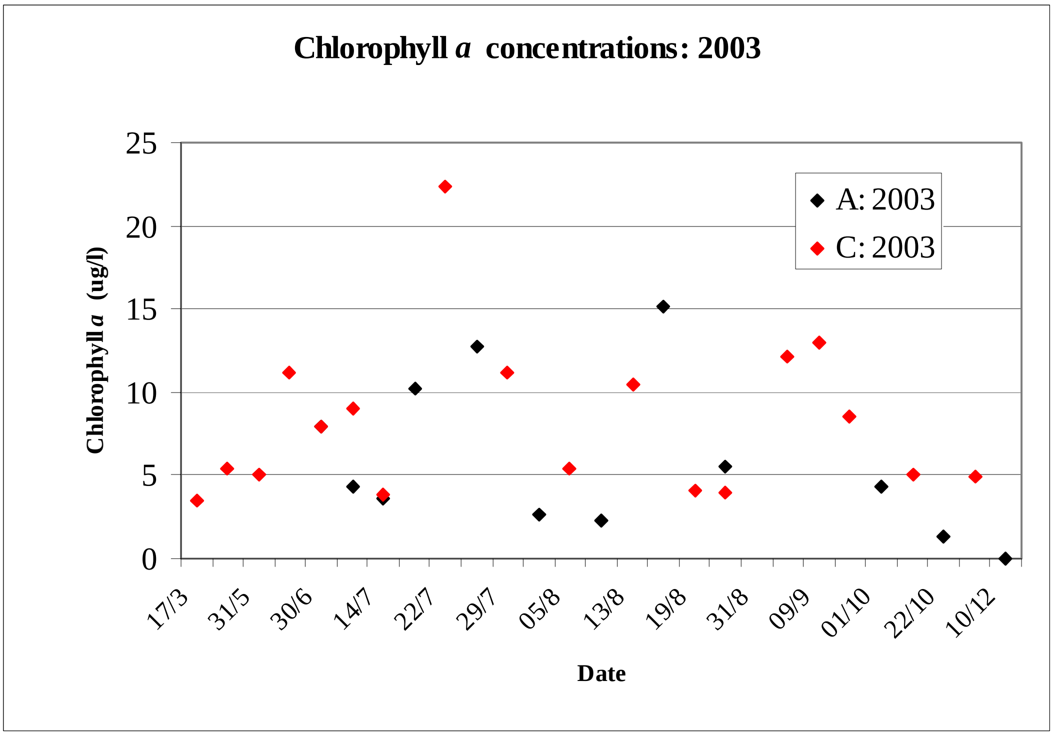


Fig 4.2 Chlorophyll *a* concentrations for sites A and C for 2000 and 2003

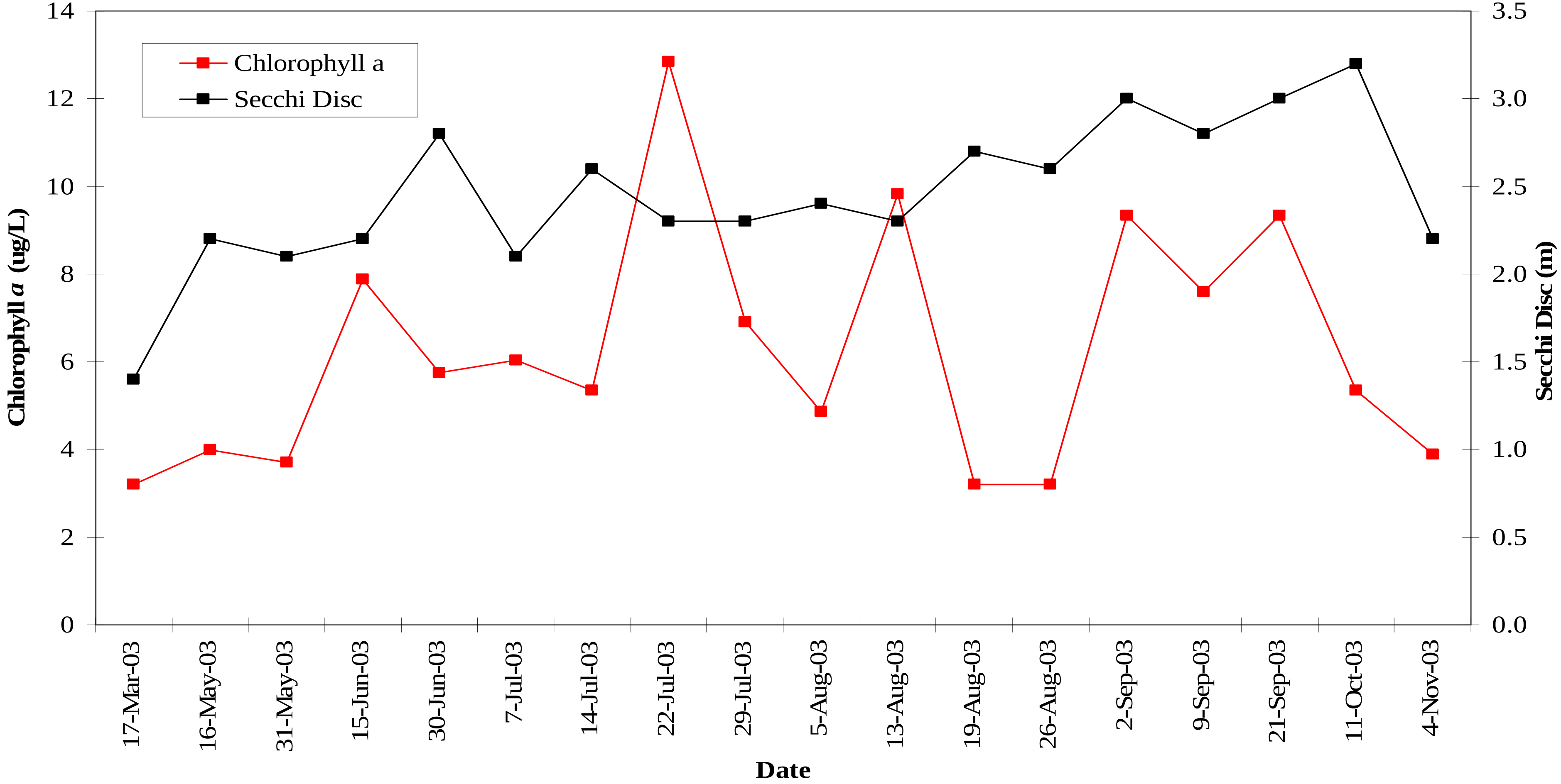


Fig 4.3 Chlorophyll *a* v Secchi Disc, 2003

4.3 Temperature

Fig 4.4 shows trends in temperature between November 2001 and December 2003. This highlights the seasonal variation in water temperature and also shows that summer 2003 was somewhat warmer than the previous summer. Weekly monitoring of temperatures also indicated that 2003 had higher water temperatures than 2000-2003. A maximum temperature of 22.4^{0}C was observed at Site D on 12/8/03. A temperature *vs* depth profile taken at the Hog Island Deep (EPA station C) in August 2001 indicated a drop of 1.4^{0}C between the depths of 6 and 10m (Fig 4.5). Slight thermal stratification has been previously recorded at this site in July 1995-1999 (Bowman, 1998, 2000).

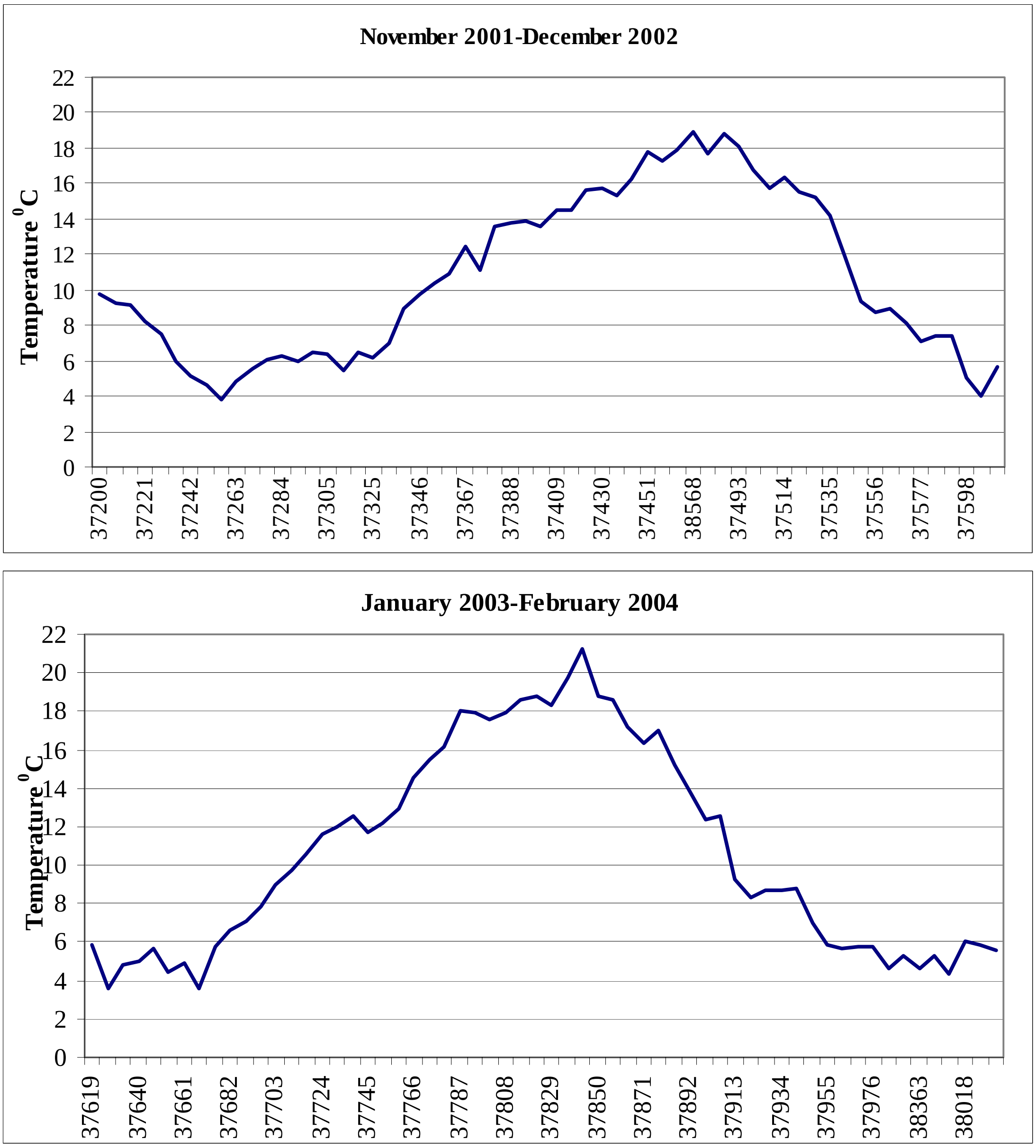


Fig 4.4 Temperature in Lough Key, November 2001- February 2004, EPA data.

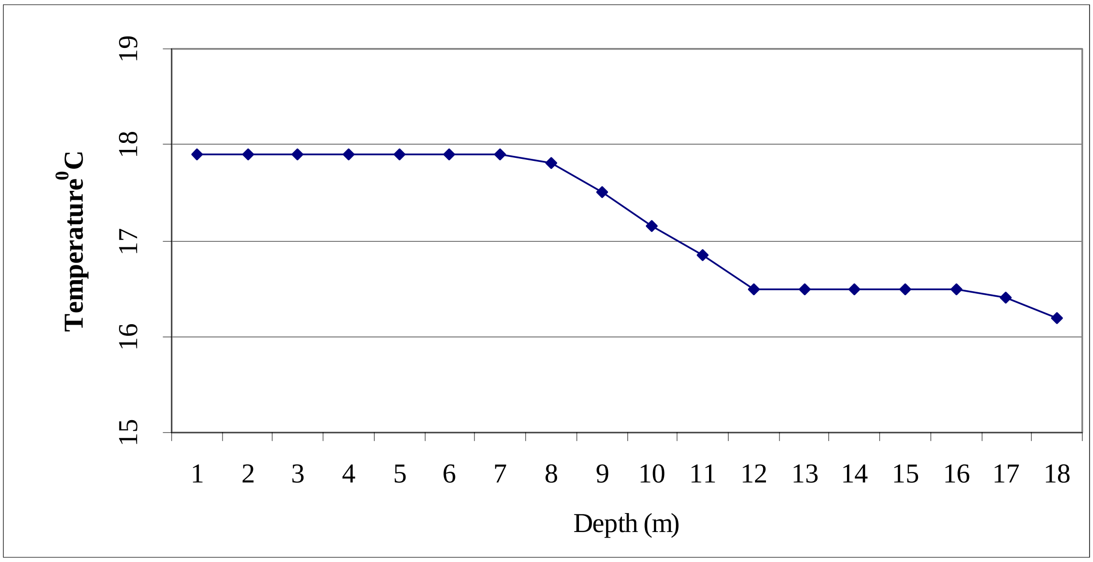


Fig 4.5 Temperature/Depth profile, Lough Key, August, 2001

4.4 Phosphorus Results

Appendix 4 gives water quality data for Lough Key (EPA), the Boyle River (RCC/ Lough Ree-Lough Derg project data) and also shows effluent flow, total phosphate mg and phosphate loadings/year for Boyle Sewage Treatment Plant in 2001, 2002 and 2003. Table 4.1 below shows range and mean total P (mg/l) in Lough Key from 2001 to 2003. The results are somewhat skewed due to occasional high values obtained in analysis (Appendix 4). They do however show a significant decrease in mean total phosphorus levels over the project period.

Table 4.1 Mean total P mg/l and range total p mg/l in Lough Key, 2001-2003

Year	**2001**	**2002**	**2003**
Mean total P mg/l	0.183	0.040	0.027
Range total P mg/l	0.020 - 2.250	0.020 – 0.182	0.014 – 0.061

TP (total phosphate) loadings/m^2 from Boyle Sewage Treatment Plant for the project years 2001-2003 are outlined in Table 4.2. Weighted mean total phosphate concentrations for Boyle STP treated effluent were 0.82 mg in 2001, 0.83 mg in 2002 and 1.22 mg in 2003. This is considered to be the main source of phosphorus in the lake catchment.

Table 4.2 Total phosphate loads (Boyle STP) P g/yr and total phosphate loads P/m^2/yr

Year	**2001**	**2002**	**2003**
TP g/yr	2902	745	1011
TP g P/m^2/yr	0.322	0.083	0.112

Fig 4.6 shows Vollenweider's relationship between annual phosphorus loading (g P/m^2 yr^{-1}) and ratio of mean depth (Z) to hydraulic residence time (τ_ω) for the 'permissible' and 'excessive' steady state concentrations of phosphorus (0.01 and 0.02 mg P m^{-3}). Lough Key phosphorus loadings for 2001, 2002 and 2003 are represented alongside the 1976 estimated phosphorus load for the lake (Toner, 1979).

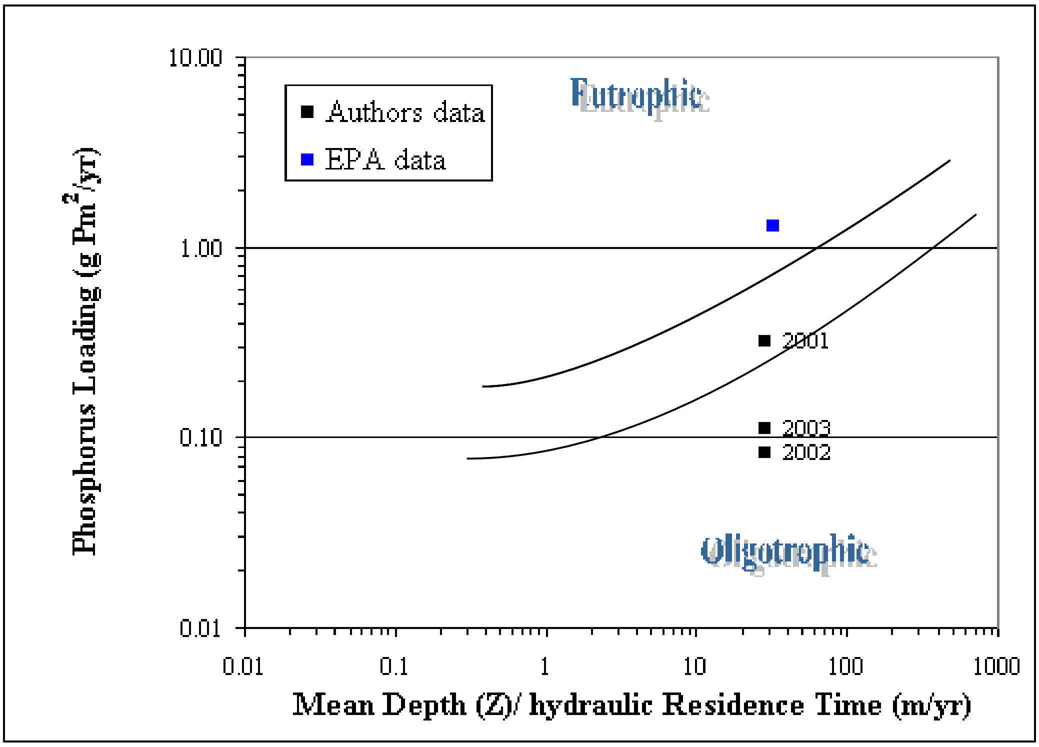


Fig 4.6 Vollenweider's relationship between annual phosphorus loading and ratio of mean depth (Z) to hydraulic residence time for mesotrophic state concentrations

This graph shows that the total P loadings in 2001 are within the mesotrophic range for Lough Key. In that year the EPA results for total P levels within the lake were mostly either moderately mesotrophic or strongly eutrophic according to OECD trophic classification (OECD, 1982). The EPA 2001 data differed significantly from results in 2002 and 2003 (Mann-Whitney, $p < 0.01$), when some results fell within oligotrophic levels (< 30 TP mg/m^3). These datasets are corroborated by the results in

Fig 4.6 for those years, showing that TP loadings for Lough Key are within the oligotrophic range.

Lough Key's orthophosphate (PO_4) levels were particularly low in July and September 2003 (<5 μg/l), this probably reflects a high nutrient uptake by algae and plants due to an unusually warm summer by Irish standards. Monthly phosphorus sampling results from the Boyle River stations upstream and downstream of the STP were consistently relatively low throughout the duration of the project. Orthophosphate ranged from 1 – 26 μg/l P upstream (mean = 11 μg/l P) and from 2 – 25 μg/l P (mean = 15 μg/l P) downstream. According to the Phosphorus Regulations (S.I. 258 of 1998) both mean orthophosphate values fit into the unpolluted category for rivers. Total phosphorus varied from 16 – 45 μg/l P (mean = 32 μg/l P) upstream and from 18 – 62 μg/l P downstream (mean = 39 μg/l P). There were highly significant differences between both the total phosphorus levels and orthophosphate levels upstream and downstream of the Sewage Treatment Plant during the project period, with results downstream significantly higher than those found upstream of the plant (Mann-Whitney, $p < 0.05$).

4.5 Phytoplankton and Cyanobacteria

Table 4.3 shows the list of common taxa of planktonic algae and cyanobacteria encountered in qualitative examination of samples taken between 2000 and 2003. As this data is qualitative, it is not possible to carry out valid statistical analysis. In terms of relative abundance however, there appears to have been no increase in *Microcystis* or any other cyanobacteria either during the course of the survey or relative to previous data (Bowman 1998, 2000). The main species involved in Lough Key algal blooms are *Aphanizomenon flos-aquae* (recognisable by the bundles of trichomes visible in the water) and *Microcystis aeruginosa*. The EPA datasets also suggest that there are no definite trends in either the increase or decrease of the relative densities of phytoplankton taxa during or before the project. There was a noticeable drop in silica levels in July 2003 (EPA data, Appendix 4), which my have been due to increased uptake by phytoplankton during the good summer.

4.6 Zebra Mussel Life Stage Sampling

4.6.1 Larval/Veliger Stages

4.6.1.1 General Monitoring Programme for Larval/Veliger Stages

Larva were detected in Lough Key from the middle to the end of May each year and corresponded with water temperatures > 13^0C. Fig 4.7 shows density variation at Site B for the six annual peak weeks of larval density, i.e. from 7 July to 12 August (2000 – 2003). Of the five lake sites, this one recorded the highest veliger densities in 2000 and 2001 (20 and 17/l) and the second highest in the two subsequent years (25/l and 18). Peak densities in 2002 were recorded at Site A; 39 and in 2003 at Site C; 45. Throughout the project relative densities were at Site D. This sampling point is located inside the entrance of a jetty. Larval densities (veligers) for all five sites, from the start of significant spawning, are included in Appendix 5. Larval numbers dropped off during the autumn period, at the end of the spawning period and were detected in only low numbers in October.

4.6.1.2 Intensive Survey Work for Larval/Veliger Stages

The intensive larval survey carried out in 2001 yielded an average larval density of 14 veligers/l; this was higher than the mean result obtained in the general monitoring survey for the same week (3 veligers).

Table 4.3 Lough Key Phytoplankton 2000-2003. A list of the common taxa of planktonic algae and Cyanobacteria encountered in qualitative examination of samples from various sampling dates. Relative abundance is indicated thus: +++ = Dominant; ++ = Numerous and + = Present

Taxa	23/03/2000	04/05/2000	05/07/2000	07/09/2000	05/04/2001	04/07/2001	06/09/2001	20/03/2002	04/07/2
Cyanobacteria									
Anabaena circinalis									
Anabaena flos-aquae		+	+			+	+		
Anabaena scheremetievi									
Anabaena spiroides			+ +	+ +		+	+		
Anabaena sp.									
Aphanizomenon flos-aquae		+	+	+		+	+ + +		+
Aphanocapsa sp.									
Coelosphaerium naegelianum	+								
Lyngbya sp.						+			
Merismopedia sp.									
Microcystis aeruginosa				+ +			+ +		
Microcystis flos-aquae	+	+ +	+	+		+	+		
Oscillatoria sp.		+		+		+	+		
Chlorophyta (Green algae General)									
Dictyosphaerium pulchellum									
Eudorina elegans	+		+ +	+		+	+ +		+
Kirchneriella obesa									
Mougeotia sp.									+
Pandorina morum	+		+ + +						
Pediastrum boryanum	+ +	+	+		+	+	+		+
Pediastrum duplex	+	+	+ +	+					
Scenedesmus quadricauda									
Sphaerocystis schroeteri				+					
Ulothrix spp.		+ +	+	+		+	+		+
Volvox sp.									+

Table 4.3 (Contd.) Lough Key Phytoplankton 2000-2003. A list of the common taxa of planktonic algae and Cyanobacteria encountered in qualitative exa of samples from various sampling dates. Relative abundance is indicated thus: +++ = Dominant; ++ = Numerous and + = Present

Taxa	23/03/2000	04/05/2000	05/07/2000	07/09/2000	05/04/2001	04/07/2001	06/09/2001	20/03/2002	04/07/2002
Chlorophyta (Desmidiaceae)									
Closterium aciculare									
Closterium spp.			+			+			
Staurastrum chaetoceras									
Staurastrum spp.	+	+				+			
Cymbella sp	+				+			+	
Bacillariophyceae (Diatoms)									
Asterionella formosa	+ + +	+ +	+ +	+	+ +	+	+	+ +	+ +
Campylodiscus noricus var. hib		+							
Cymatopleura elliptica	+ +	+	+	+ +	+	+	+	+	+
Diatoma elongatum				+	+			+	
Diatoma sp.	+ +			+				+	
Fragilaria crotonensis	+			+	+		+	+	
Fragilaria sp.	+ +	+		+		+			+
Gyrosigma sp.	+	+			+	+		+	+
Melosira granulata	+	+		+ + +	+	+ +			+
Melosira italica	+	+	+	+	+			+	
Melosira varians	+ +		+		+ +	+	+	+ +	+
Nitzschia sp.							+		
Stephanodiscus sp.				+	+				+
Surirella sp.	+	+			+		+		+
Synedra acus	+ +				+		+	+	
Synedra ulna	+				+				
Tabellaria spp.	+							+	
Dinophyceae									
Ceratium hirundinella	+	+	+	+	+	+			+
Peridinium sp.		+							
Euglenophyta									
Phacus									
Chrysophyceae									
Dinobryon spp.	+ +		+		+	+			+
Mallomonas sp.								+	+
Synura sp.								+	

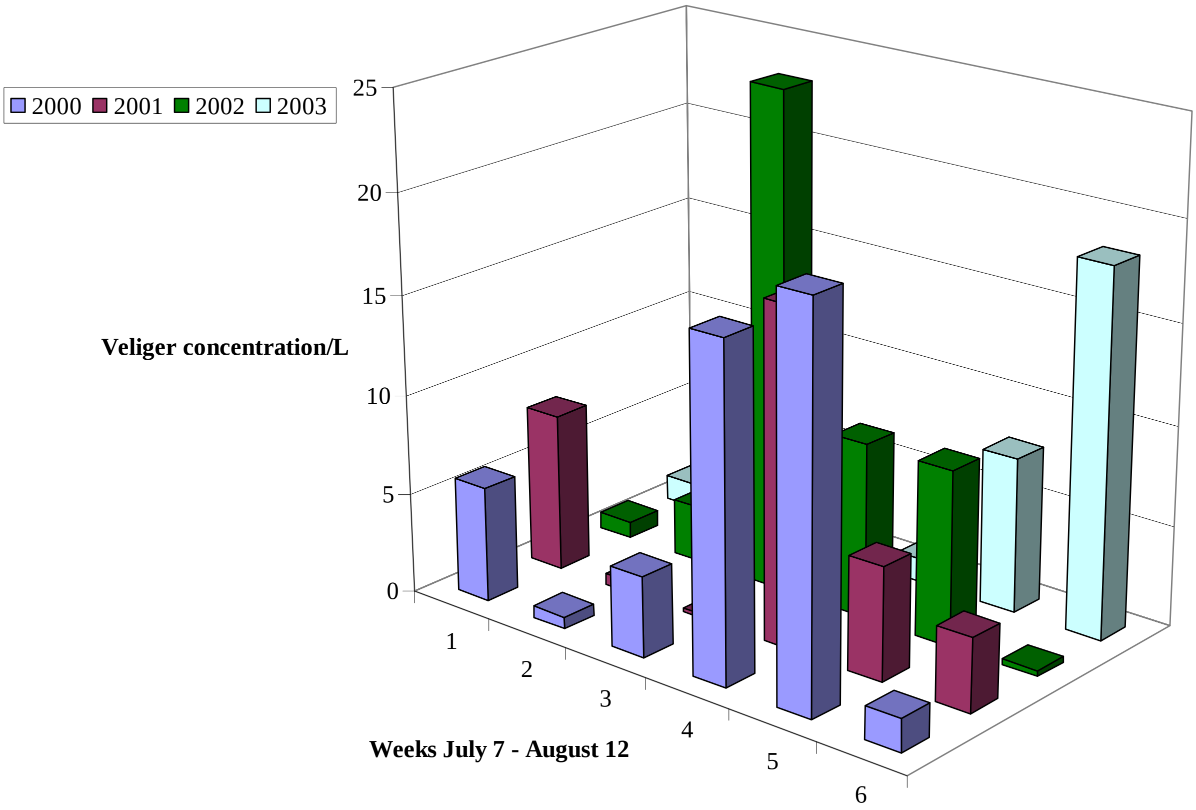


Fig 4.7 Veliger Densities at Site B (July - August 2000-2003)

4.6.1.3 Estimation of Larval/Veliger Size Distribution

Size distributions from the veliger samples in all years measured D veligers ranging from 70 µm (lower limit of mesh size, 64 µm) to pediveligers of 260 µm. In most sampling weeks, veligers >260 µm were not generally present in the plankton. Larger individuals were also occasionally recovered, including one at 840 µm sampled in September 2002.

At the start of the annual sampling period (late June/early July), the samples were dominated by early stage D-veligers and umbonate larva (70-110µm). As the season progressed larger pediveligers were seen to peak in samples before settling out. Few larvae > 260 µm were found in samples indicating that settlement had taken place by that size. Statistical analysis determined that there was often a significant difference between size distributions in consecutive weeks in 2002 and 2003 (Mann-Whitney test, $p < 0.05$). In general, the proportion of larger veligers increased from July week 4 to August week 4, with an elevated percentage also occurring during the first two weeks of September in 2002. There was no correlation between seasonal veliger density and % of veligers > 200µm, except in 2003 when a strong correlation was found ($r = 0.71$, $p = 0.02$).

Trends in size distributions over one sampling season (2003) at Site E are outlined in Fig 4.8. Size distributions for Sites B, C and E from early July to mid September, 2000 – 2003 are included as Appendix 6. Complete results for size distributions (2000-2003) can be viewed in Duggan (2001); Marshall (2002); O'Mahony (2003) and Lohan (2004).

All larval stages were also present in samples analysed from the intensive survey carried out on 10 August 2001, corresponding with the other general monitoring results for that year.

4.6.2 Settled Juvenile Sampling

Figs 4.9 and 4.10 show a general trend in settlement at Sites B and C from 2000 to 2003. Annually, the highest settlement occurred during the entire month of August (weeks 2 to 5) (Appendix 7). Settlement was low in 2002 at all five sites, peaking at 4,000 m^2 at Site B in week 3. In 2003, Site B peaked at Week 4 with approximately 170,000 settled juveniles/m^2 (Plate 4.1) – the highest settling density obtained since monitoring began in 1998. Fig 4.11 shows cumulative settlement *vs* mean larval density for the years 2001, 2002, 2003. Overall seasonal settlement in 2003 was comparable to 2000 and 2001.

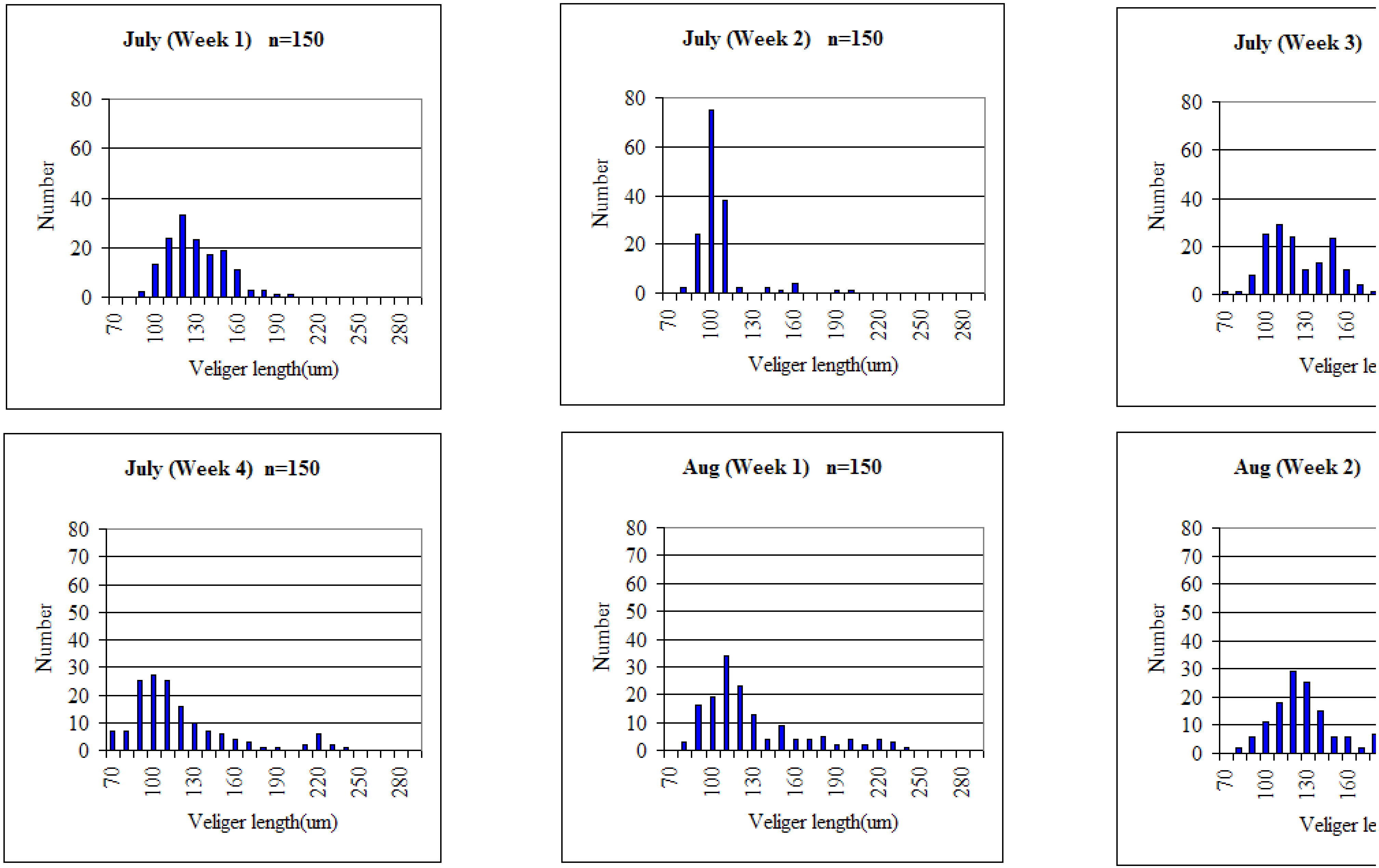


Fig 4.8 Zebra mussel veliger size distributions, July (Week 1) - August (Week 2), 2003, Site B

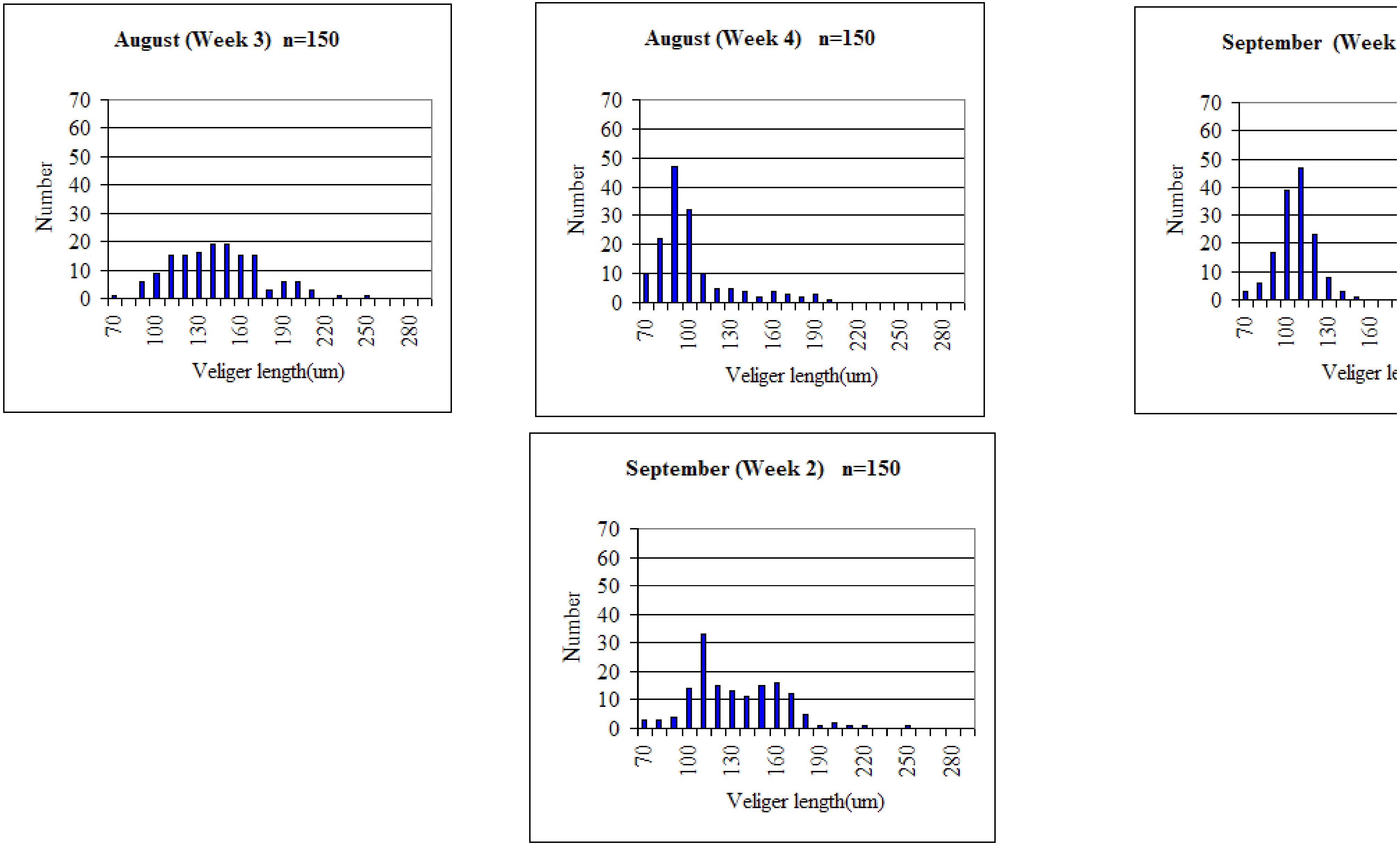


Fig 4.8 (Contd.) Zebra mussel veliger size distributions, August (Week 1) - September (Week 2), 2003, Site B

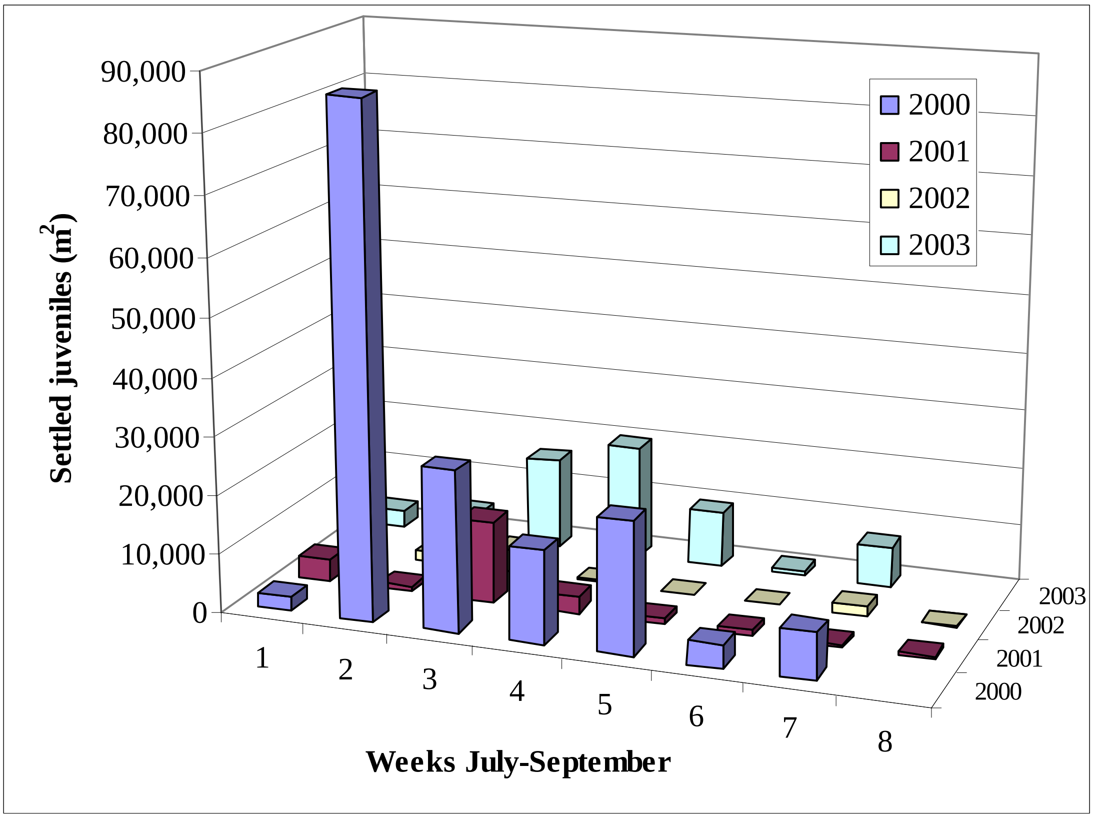


Fig 4.9 Settlement at Site B, 2000 - 2003

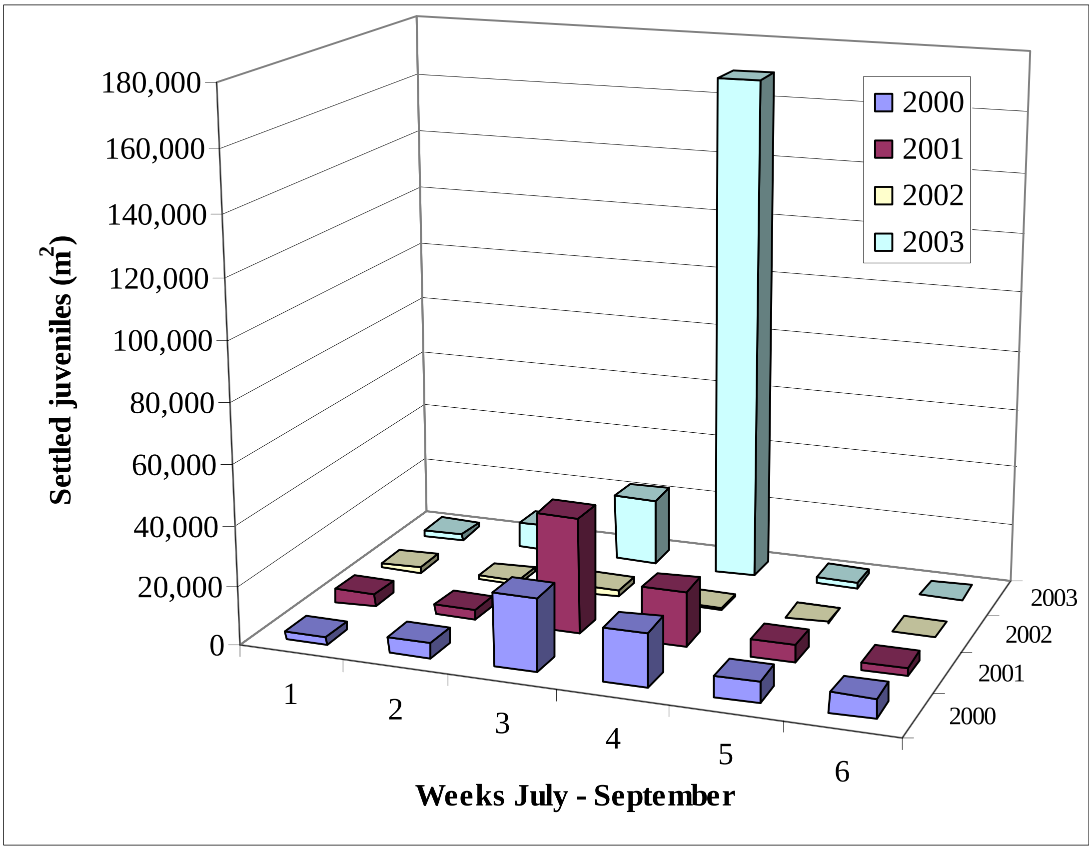


Fig 4.10 Settlement at Site C, 2000 – 2003

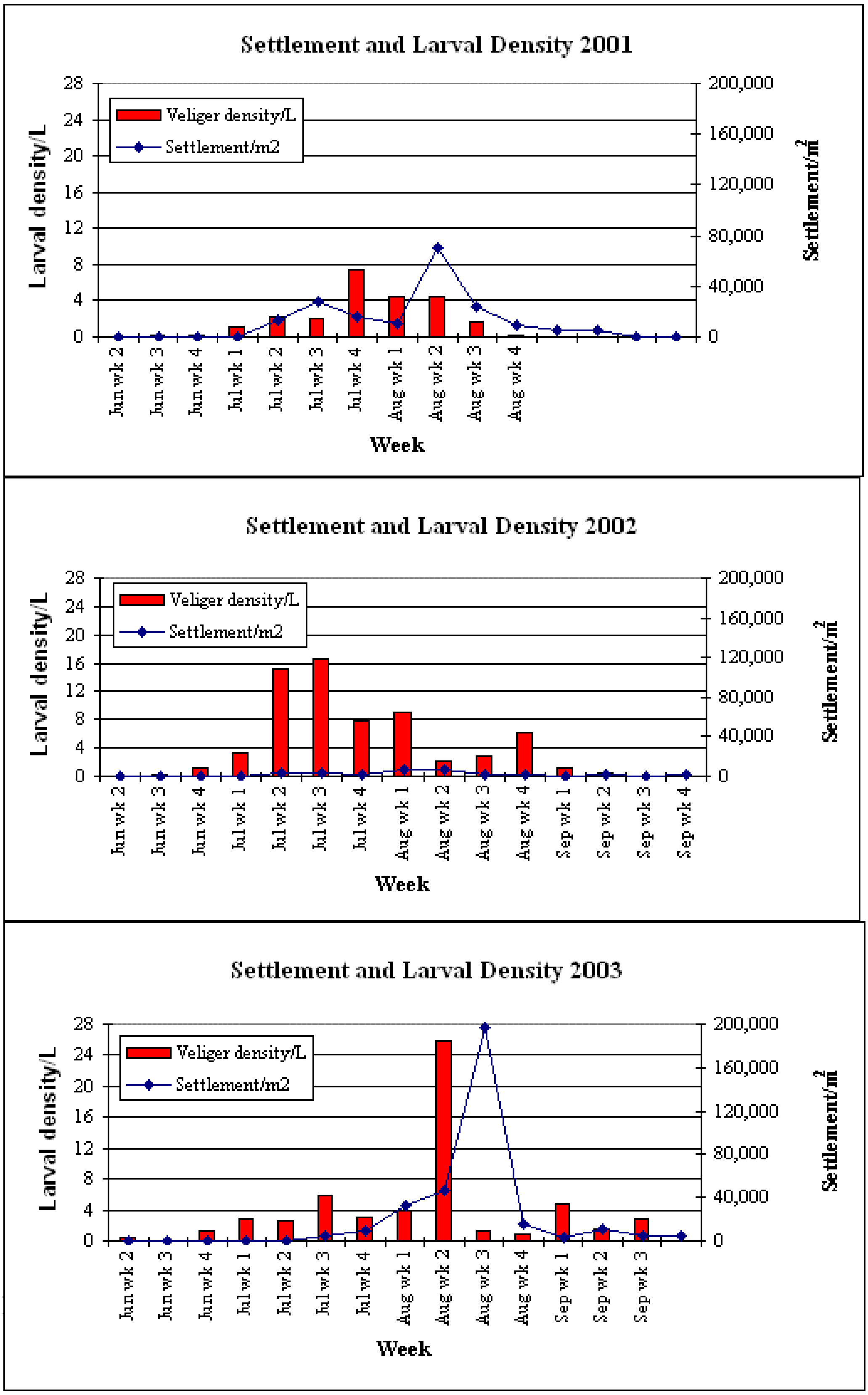


Fig 4.11 Settlement vs larval density (cumulative values) 2001-2003

Overall settlement was very poor in 2002 (maximum, 4,000/$m^{2,}$ Site B, August week 2). Peak settlement in 2001 and 2002 occurred two weeks after peak larval density. In 2003, relative settlement was high and appeared to occur only one week after peak larval densities. Statistical analysis showed larval densities (week n) *vs* settlement (week n +1) to be highly positively correlated in 2003 ($r = 0.96$, $p = <0.001$). No correlation was found in 2001 or 2002. The proportion of veligers > 200 µm was highly correlated with settlement (week n+1) in 2003 ($r = 0.85$, $p = 0.002$). No correlation existed for other years. There appeared to be no overall difference in settlement obtained between plates suspended at 3m and those at 4m at Site A in 2002.

Results from seasonal settlement plates were low due to periphyton growth and did not relate to cumulative settlement from biweekly plates. For example, at Site C the seasonal settlement plate for 2003 had far fewer juveniles attached (total for 15 x $15cm^2$ plate = 6) than was present on the August week 3 biweekly sample plate (mean = $17/cm^2$). For this reason, seasonal plate data have not been included in this report. The size range of settled juveniles varied from 200 – 400 µm, with occasional larger zebra mussels up to 1.5 mm in length.

4.6.3 Adult Sampling

4.6.3.1 Snorkel Surveys

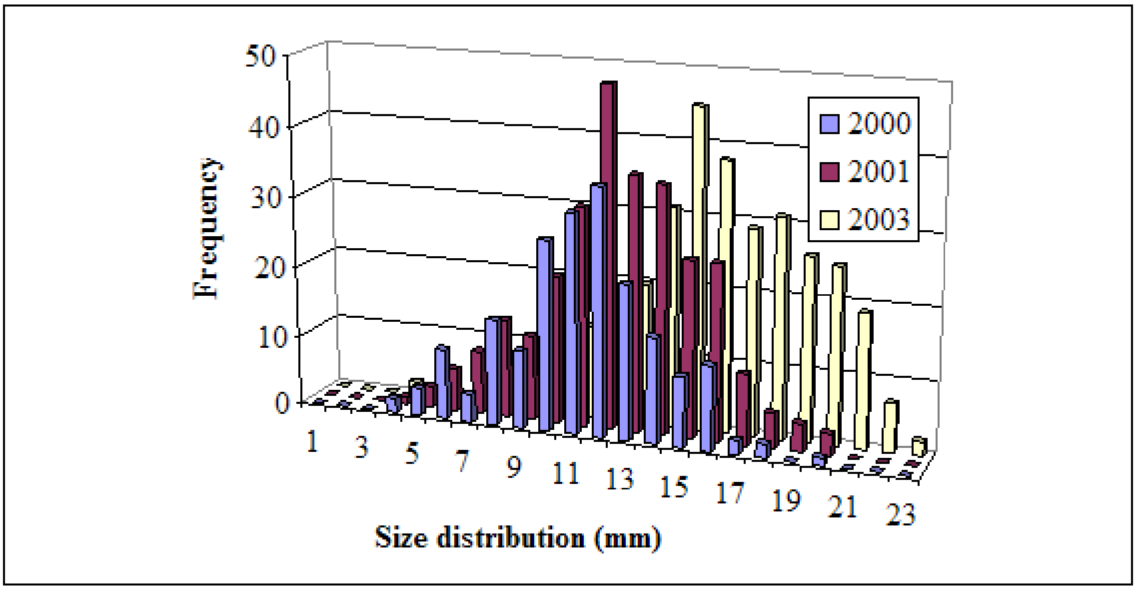
Results for this section include size distributions, biomass results and statistical analysis and photographs. Statistical analysis involved comparing various datasets; between-year combined sites for particular substrates; between year individual sites for particular substrates.

- **Stoney Substrates**

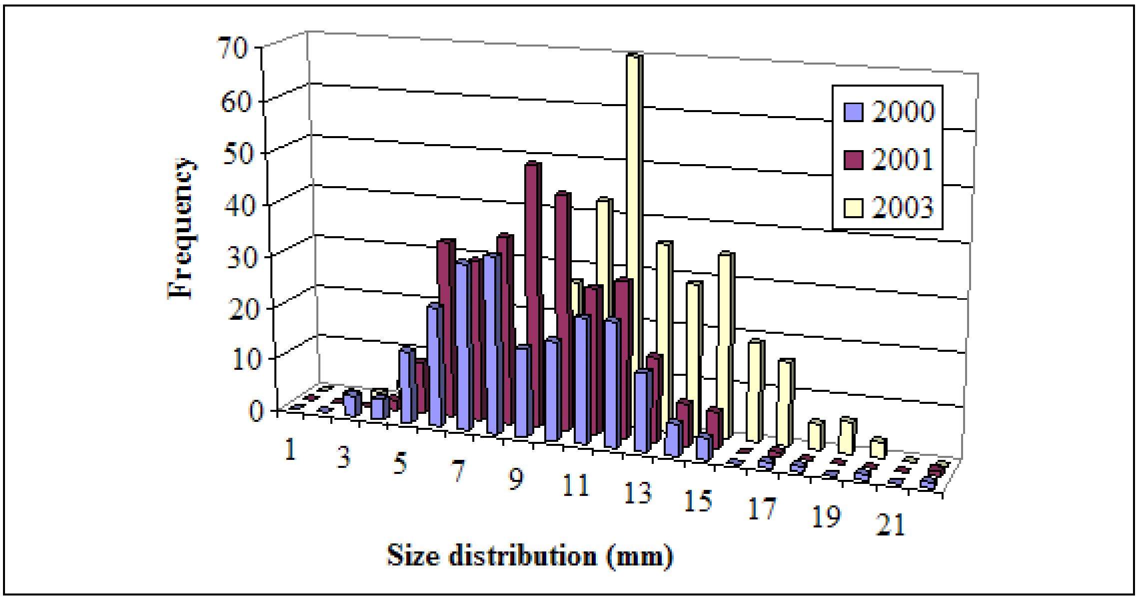
In 2001 and 2003 the percentage cover of zebra mussels on stone at snorkel sites varied from 40-100 per cent (Appendix 8). Plate 4.1 shows 95 per cent zebra mussel cover on stone.

Plate 4.1 Zebra mussels on stone

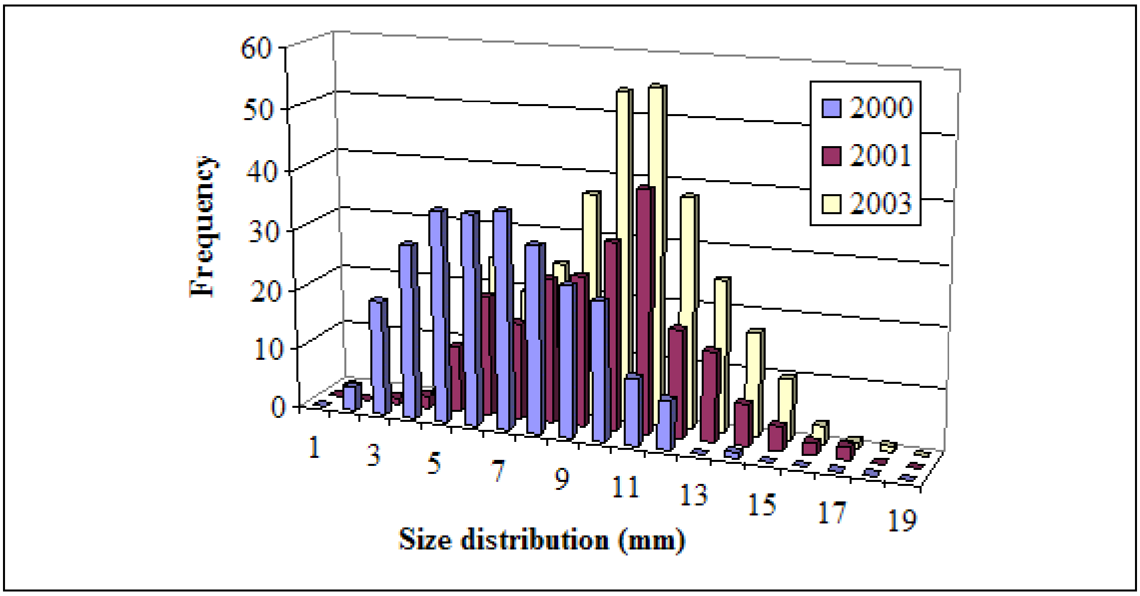
Individual sizes of zebra mussels measured during the project varied from <1mm to 34 mm, which reflects the presence of at least three main year classes (0+, 1+ and 2+ age cohorts). Fig 4.12 shows the size distribution of zebra mussels on stones from Sites 2, 6 and 7 in early August 2000, 2001 and 2003.



Site 2



Site 6



Site 7

Fig. 4.12 Size distributions of adult zebra mussels at sites 2, 6 and 7 for 2000, 2001 and 2003

New settlement of zebra mussels was taking place at the time of sampling in each of those years (Appendix 7). Only zebra mussels of 1mm or more were measured in samples. It is difficult to separate age cohorts present due to merging of modes, but Fig 4.12 indicates the presence of at least two modes. The 3-9mm (approx.) category represents settlement from the previous summer and autumn and are categorized as the 1+ cohort. Zebra mussels greater than 10mm were considered to be 2+ individuals. Occasionally, a large individual >22mm, was found with a worn shell and probably represented the 3+ category. The 2000 and 2001 samples are well represented by 1+ and 2+ modes. The 2003 samples appear to have low numbers of 1+ individuals, which correlates with the poor settlement in 2002 (Fig 4.11). 2+ individuals attained a larger size in 2003 than in other years (23 *vs* 20mm). This may be due to the increased summer water temperatures (Fig 3.4). Fig 4.13 illustrates size distributions (Rockingham jetty) for every second month from April 2003 to February 2004. October 2003 and February 2004 samples show high numbers of 1 mm zebra mussels, representing high rates of successful settlement in late summer 2003.

Fig 4.14 shows the similarity of size distributions at 0-1m and at 12-13m depth at Site 7. These were not significantly different in mean size (Mann-Whitney, $p > 0.05$). At depth zebra mussels were discovered at 17.5m on a rocky ridge near the centre of the lake (size distribution, 1 -13 mm length). The quality of shell at these greater depths was similar to that in shallower water, both in terms of colour and hardness.

The biomass obtained in 2000 cannot be directly compared with that in the other two years of snorkel survey work, due to the different method used. It is however possible to compare 2001 with 2003. While some variation existed within and between sites, there was no overall significant difference in zebra mussel biomass in the snorkel sites between those years (ANOVA, $p > 0.05$). The mean biomass for 2001 was 297g/ 25 cm^2 (4.74 kg/m^2) while the mean for 2003 was 290g/25cm^2 (4.64 kg/m^2).

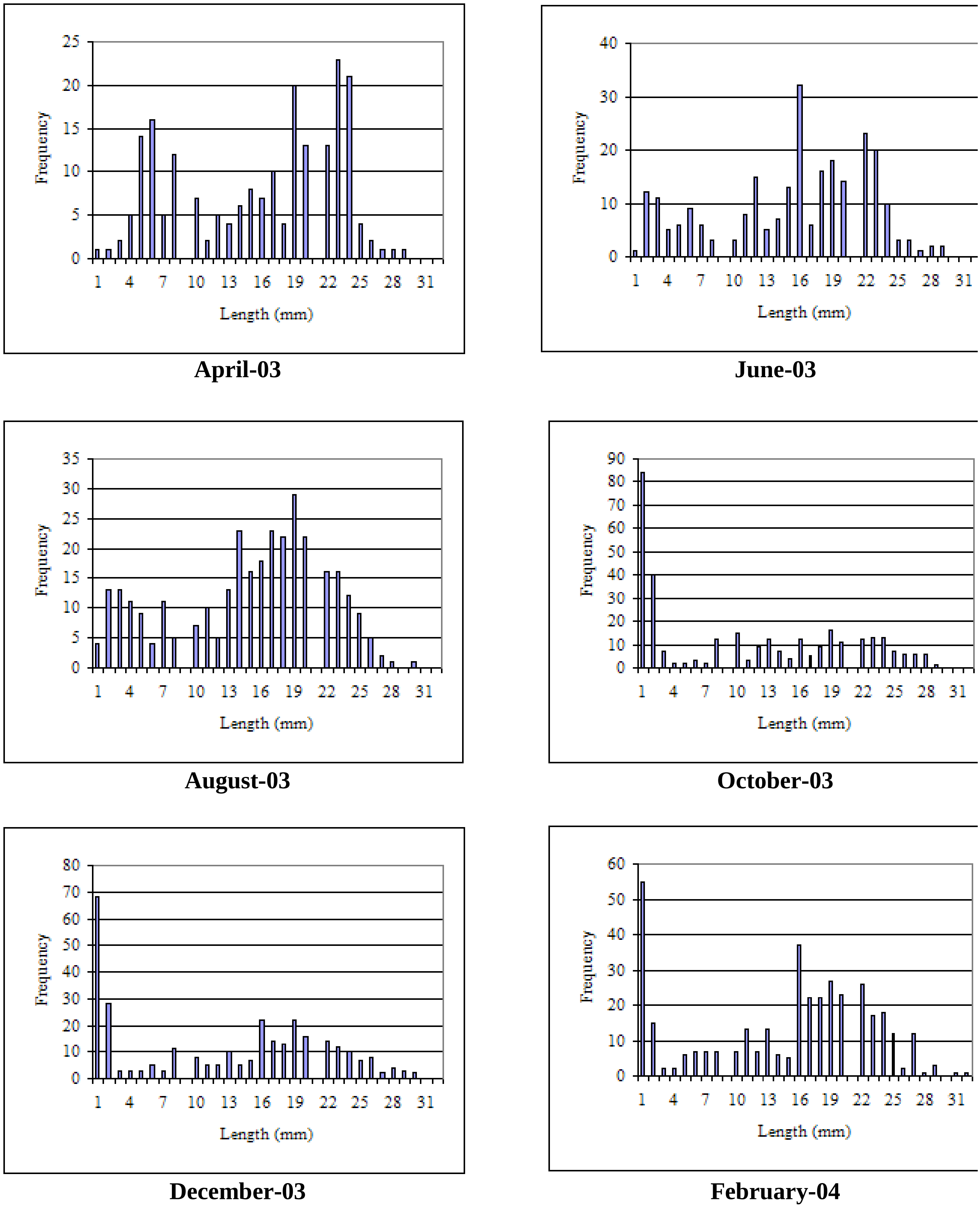


Fig 4.13 Seasonal size distribution of adult zebra mussels at Rockingham, Lough Key

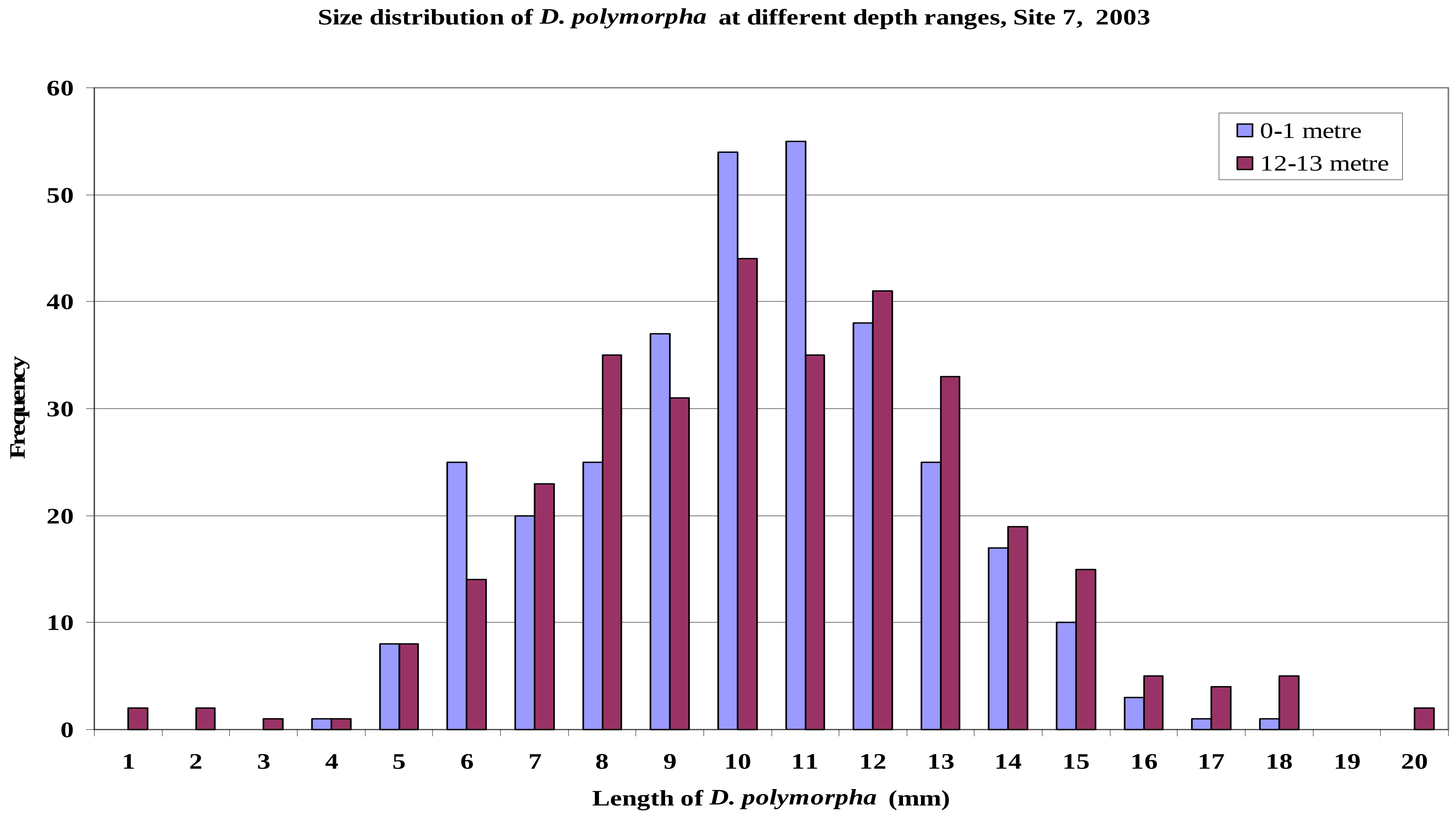


Fig 4.14 Size distribution of *D. polymorpha* at different depth ranges, Site 7, 2003

- **Zebra Mussels on Reeds, Rushes and other Aquatic Plants**

Many aquatic plants were noted as zebra mussel settlement surfaces in Lough Key including the algae *Cladophora*, the moss *Fontinalis antipyretica* and annual and perennial vascular plants. Submerged tree roots of alder *Alnus glutinosa* and branches of ash *Fraxinus excelsior* were also found with zebra mussels attached. All plants within the lake showed varying degrees of colonisation by zebra mussels. Table 4.4 outlines the most important plants to which zebra mussels were found attached in Lough Key. Not all of the sites surveyed by snorkel, dive or ROV surveys had all of these plants present. Plants were also noted during grab sampling analysis.

Table 4.4 List of plants with zebra mussels attached, in order of importance, Lough Key

Phragmites australis	Common reed
Schoenoplectus lacustris	Common club-rush
Nuphar lutea	Yellow water lily
Equisetum fluviatile	Water horsetail
Elodea canadensis	Canadian waterweed
Potamogeton perfoliatus, P.lucens, P. natans	Pondweed species
Sparganium emersum	Unbranched bur-reed
Lemna triscula	Ivy-leaved duckweed
Cladophora	Filamentous alga

The old stems of the common reed *P. australis* had the greatest biomass of *D. polymorpha*. Mean biomass per plant (random 10 plants) in 2000 was 478 g and 551g in 2001. There was no significant difference between overall biomass (combined sites) in 2000 and 2001 (t-test, $p > 0.05$).

New *Phragmites australis* plants showed a biomass of <1 gram on individual plants (Plate 4.5), while plants in their second year or older showed a biomass up to 580 g per individual. The high settlement of zebra mussels on old *Phragmites australis* in 2000 and 2001 resembled corn on the cob (Plates 4.4 and 4.5), particularly at Site 1. By February 2002 this phenomenon was surveyed on only one broken stem, which had large zebra mussels concentrated towards the top of the broken stem (video survey). At this site, old dead *Phragmites* stems recorded lying on the substrate, and old and new erect stems were all without any zebra mussels attached.

Plate 4.2 Zebra mussels covering old *Phragmites* stem, showing ‘corn on the cob’ effect

Plate 4.3 Transverse section of *Phragmites* stems, showing extensive fouling by zebra mussels on old stem (right) and <1g fouling of new stem (left).

In 2003 results from three of the snorkel sites (Sites 1, 4 and 7) showed a very highly significantly lower cumulative biomass for the ten stems sampled in 2003 than in 2001(ANOVA, $p < 0.001$) (Table 4.5).

Table 4.5 Biomass of zebra mussels (g) on ten old *Phragmites* at Sites 1, 4 and 7 in 2001 and 2003.

Year	Site 1 Biomass (g)	Site 4 Biomass (g)	Site 7 Biomass (g)
2001	3506	939	806
2003	48	23	31

Throughout the survey the common club rush, *Schoenoplectus lacustris* showed a low density of settlement; in 2001 the biomass was significantly lower than old *Phragmites australis* (P <0.01) and not significantly different to new *Phragmites australis* (ANOVA, p >0.05). ROV work in 2001 recorded >95 percent of *Schoenoplectus lacustris* with no zebra mussels attached.

Appendix 2 outlines the aquatic plants recorded by the Lough Key ROV survey. Edited video survey work includes footage of zebra mussels on various aquatic plants and also on *Cladophora* alga. Zebra mussels were noted attached to the concentric nodes on the stems of *Equisetum fluviatile*.

Exposed rhizomes of perennial plants (*Phragmites, Schoenoplectus, Equisetum* and *Nuphar*) were used as substrates by zebra mussels. In the case of *Phragmites* and *Schoenoplectus*, they were often seen to follow a rhizome line parallel to the plant. This was particularly apparent in both autumn and winter video surveys. The multifaceted rhizomes of *Nuphar* also provided a relatively high surface area for settlement in soft substrates. Spring video work showed that zebra mussels can spread from the rhizomes up the petioles of this plant as they develop their annual growth. Early video survey work in 2001 showed high densities of zebra mussels on old *Phragmites australis*. The 2002 and 2003 film footage mirrored snorkel survey results by indicating that the rate of plant colonisation had dropped dramatically. Although small clusters of zebra mussels were observed on the base of the stems, only occasional individuals were noted higher up on stems. It should be noted that there appears to be a baffling effect in reed beds, restricting the dispersal of zebra mussels shorewards. Reeds on the outer 1 metre margin of reed-beds (deeper waters) supported the greatest densities of zebra mussels, while 5 metres inshore from the outer reed bed margin, zebra mussel burden drops to <1 gram per individual old reed. Several randomly selected reed beds in Lough Key and other lakes in the Shannon system showed similar results with zebra mussel densities decreasing with increasing distance inward from the outer periphery of the reed bed.

Annual plants, e.g. Canadian pondweed (*Elodea canadensis*) and duckweed (*Lemna trisulca*), provided only a temporary substrate and normally supported less than one gram of zebra mussel biomass per plant. These were not included in biomass analysis after 2001. *Cladophora* was sometimes present on stone and mud substrates and also draped over the stems of emergent reeds, rushes and horsetails. It was often found growing on top of zebra mussels attached to stones.

Although biomass estimation of aquatic plants was not a part of this project, it was noted that there were definite increases in the densities of macrophytes and algae at some of the snorkel sites. This included *Potamogeton perfoliatus* at Site 2 and *Cladophora* at Site 8.

- **Zebra Mussels on *Anodonta anatina***

  The 2000 snorkel survey sampled one recently dead *Anodonta anatina* at Site 2. This contained decaying flesh and was a small specimen (estimated age, 3 years and biomass 2g) burdened with 7g of zebra mussels. Every other *Anodonta* sampled in 2000, 2001 and 2003 (n = 719) was a dead shell. In 2000 all shells sampled were fouled with zebra mussels (mean fouling = 30.5g/*Anodonta* shell).

  In 2001 only two shells in two hundred and forty sampled from the eight sites were without fouling. In that year, the video survey the number of *Anodonta* shells varied from 0 – 12 m^2 , with an average of 2m^2. Snorkel survey work estimated the number of shells/m^2 at Sites 1-8 in 2001 (3–9 m^2) and 2003 (<1-5 m^2) (Appendix 8).

  No *Anodonta* shell sampled in 2003 was without attached zebra mussels. The percentage of *Anodonta* shells contributing to overall potential substrate for zebra mussel colonisation in shallow areas of the lake was estimated (during the video and transect substrate surveys) at 1 per cent (Fig 3.5 and 3.6).

Zebra mussel cover of exposed parts of *Anodonta* shells was 100 per cent at most sites in 2001 and 2003. At one site cover was only 80 percent, with the encrusted *Anodonta* shells resembling hedgehogs in the soft substrate. It was noted that loose druses of zebra mussels were present on many of the shells. Over time the shells became submerged in the mud substrate, meanwhile the zebra mussels are spreading out and colonizing the soft substrate. There was a significant decrease from 2001 levels in biomass of zebra mussels colonising *Anodonta* shells at all snorkel sites (P <0.05). In 2003 Site 1 had the highest loadings with a mean of 21g/*Anodonta* shell. In 2001, the highest mean loadings were 55g/*Anodonta* shell, found at Site 4. This site also had the highest mean loading in 2000 (57g/*Anodonta* shell). In 2003 the mean loading at this site was only 18 g/ *Anodonta* shell.

In 2003 minimum and maximum levels of fouling on individual shells (total number examined 240) were < 1 g and 106g respectively. This was comparable with parallel results of <2g and 125g in 2000; 1g and 103g in 2001.

Snorkel surveys and video footage in 2003 showed that many *Anodonta* shells were becoming submerged in the substrate and that zebra mussel druses extended onto mud from sinking *Anodonta* shells. Some of the *Anodonta* shells had loose attachments of zebra mussels, which had been spreading outwards onto the mud. Other shells were partially coated with the byssal plaques of zebra mussels. Plates 4.4 and 4.5 show zebra mussel coated *Anodonta* shells.

Plate 4.4 Zebra mussels on edge of large *Anodonta* shell with extensive byssal plaques left by previous zebra mussel attachment.

Plate 4.5 Zebra mussels on *Anodonta* shells

4.6.3.2 Transect Survey- Sampling Density and Biomass of Adult Zebra Mussels

A small pilot sampling programme of the effectivenss of grab sampling versus scuba diving sampling was carried out where the sediment categories moved towards transition and mud, i.e. Sites 3 and 4. The southeast transect was chosen for this study at a depth interval of 4 – 5 metres. The results showed that both methods of analyses agreed that the substrate was the same. The grab sampler picked up small pebbles with zebra mussel druses attached and the remainder of the sample was mud. The diver also recorded the same sediment type by visual observation.

The results of the survey show that the total number of zebra mussels recorded per metre^2 using a grab is 97 per cent of the total recorded by the scuba diving methodology (Table 4.6).

Table 4.6 Results of trial for scuba diving *vs* grab sampling methods

	Scuba Diving	**Grab**
Total No.	153, 231, 296	129, 68, 67
Mean Total no.	227	88
Quadrat (m^2)	0.0625	0.025
Total No. (m^2)	3627	3520

Appendix 9 gives the zebra mussel biomass and numbers for each of the transect samples. This data was used, in conjunction with total area for each depth interval, to calculate total number and biomass of zebra mussels in Lough Key.

The total number of zebra mussels in Lough Key estimated by this method is 34 x 10^9 with a total biomass of 4.4 x 10^6 kg. The mean density of zebra mussels over the total lake bed was 3,900m^{-2}, with a biomass of 520g/m^2. The highest mean density (6,800 zebra mussels/m^2 and mean biomass (1.05kg/m^2) was found in the first 3m of depth. As there was no significant difference in biomass of zebra mussels between 2001 and 2003, the number and biomass estimated in 2001 is considered valid for the duration of this project survey (2001-2003).

4.6.3.3 Filtration Capacity of zebra mussels in lake

In this study, a filtering rate of 44.4 ml/g WTM^{-1} (wet tissue mass, shell plus tissue) per hour was derived by taking the mean of five independent East European surveys carried out at similar summer temperatures (Kondratiev, 1962; Stanczykowska, 1968; Lvova, 1977; Karatayev and Burlakova, 1993; Karatayev and Burlakova, 1995: all reviewed in Karatayev *et al*., 1997). The product of the biomass and the filtering rate was multiplied by 24 (hours) to give the daily filtration capacity of the zebra mussels in Lough Key. The lake volume (46×10^6 m^3) was divided by the filtration capacity to estimate the theoretical time taken in days for the *Dreissena* population to filter the entire lake during the summer period.

Biomass of zebra mussels in Lough Key = 4.4×10^6 kg
Filtration rate = 44.4 ml/g zebra mussel/hr
Filtration rate/hr Lough Key = 19.5×10^6 l
Filtration rate/day = 4.7×10^9 l
= 4.7×10^6 m^3
Lake volume = 46×10^6 m^3

Therefore the zebra mussel population in Lough Key filter a volume of water equivalent to the entire volume of Lough Key approximately every ten days, once water temperature exceeds 10^0C (Reeders and Bij de Vaate, 1990).

Chapter 5. Discussion

5.1 Introduction

The focus of this report was to assess the relationship between lake nutrients and the zebra mussel population in Lough Key from 2001 to 2003. The original hypothesis was that the commissioning of the new Boyle Sewage Treatment Plant, complete with a new phosphate removal system, would result in a reduced phosphorus load and subsequently there would be a decrease in total phosphorus levels in the lake. If phosphorus became a limiting nutrient in the lake, phytoplankton stocks would diminish thus affecting a major food source for zebra mussels. This in turn could result in a decrease in the Lough Key zebra mussel population.

Conversely, the impacts of zebra mussels on the pelagic parameters of water quality that are used to assess trophic status have been well documented (Stanczykowska and Lewandowski, 1993; Holland *et al.*, 1994; Johengen *et al.*, 1995; Nalepa *et al.*, 1999; Maguire *et al.*, 2003). Zebra mussels have been described as ecosystem engineers altering both ecosystem structure and function including nutrient cycling (Karatayev *et al.*, 2002). This means that changes in total phosphorus levels in Lough Key may also be attributed to the presence of the zebra mussel; in this way the population could be ultimately self- limiting. The physical and chemical water parameters that were monitored and also collated from other sources for this project were specially selected to assess any changes to the trophic status of Lough Key during the course of the project.

The assessment of impacts to the zebra mussel population was made during the course of the project with the total numbers/biomass in the lake estimated and numbers compared with previous work (Lucy and Sullivan, 2001). This population estimate made it possible to assess the filtration rate of the zebra mussel population and the potential impacts the species themselves may have on nutrient levels in Lough Key.

The discussion is divided into three main sections. The first relates to the trophic status of the lake; this leads into a second, which deals with the zebra mussel populations and the third tackles potential links between this invasive species and nutrient levels in Lough Key. A final section targets the difficulties the zebra mussels pose in defining reference conditions in terms of the Water Framework Directive (2000).

5.2 Trophic Status of Lough Key

From the data available (Bowman, 1998; Bowman, 2000; Lucy (unpublished); Lucy and Sullivan, 2001; this work) it would appear that from July 1998 onwards, during the summer months at least, concentrations of total phosphorus and chlorophyll *a* have remained low while transparency initially increased in 1999 and has remained relatively high. The change in these values coincides with the expansion of the zebra mussel population in Lough Key during the late 1990s (Lucy and Sullivan, 2001). These changes occurred two years before the commissioning of the new Boyle Sewage Treatment Plant.

In terms of trophic status (OECD, 1982) during the project period: some transparency levels exceeded 3m (oligotrophic minimum, obtained during late summer/autumn 2003) while most were in the mesotrophic range; chlorophyll *a* levels fit within the oligotrophic range (<8 mg/m^3), except during seasonal blooms and total phosphorus levels were within mesotrophic range (10-35 mg/m^3).

5.2.1 Transparency

Zebra mussels remove a wide range of particulate matter from the water column and a corresponding increased water transparency related to the arrival of this invasive species has been recorded since 1999. Although increases in water transparency are associated with decreased chlorophyll *a* levels they may also reflect the removal of suspended solids, bacteria and other particulate matter by zebra mussels in the size range between 1um and 150um (Horgan and Mills, 1997). Results for transparency recorded by Toner (1979) averaged 4.5m in August 1976, in excess of any values obtained in subsequent years' monitoring. Although phytoplankton levels were kept in check by the zebra mussel population from 1998 onwards, the previous high levels of transparency obtained in 1976 have not been repeated. In 1976 chlorophyll *a* levels were in the oligotrophic category, and relatively low nutrient levels were present. It is presumed that this difference in transparency levels is a reflection of the deterioration in water quality in Lough Key from that time onwards. This marked increase in the total phosphorus and chlorophyll *a* levels in the lake was noted by

Bowman (1998). It may also relate to an increase in the release of humic acids due to ground disturbance in the catchment, notably the development of a new section of the main Sligo-Dublin road (N4) in the late 1990s.

A further section of the discussion will highlight that the 2003 high transparency values were not accompanied by a similar increase in the zebra mussel population. Instead other environmental factors may be involved in these results, most notably the low rainfall and extremely calm conditions. Peaty soil is also common in the land surrounding Lough Key. The release of humic acid into lakes typically results in low water transparency due to its yellowish-brown colour (EPA, 2001). The high transparency and low colour readings (EPA data) in autumn 2003 were taken after a period of prolonged dry weather when there would have been little or no impact from peatland drainage. In fact 1976 was also a very dry summer and may have been partly responsible for the high secchi disc reading obtained by Toner (1979). The increase in secchi disc readings recorded during the present study was accompanied by a corresponding drop in colour (Appendix 4), due to the low land runoff during an extremely dry summer.

It is likely that the relatively low reduction in transparency relative to the drop in chlorophyll *a* levels, subsequent to zebra mussel invasion is due to high natural colour in the waters of Lough Key. These high Hazen levels may explain why there was no correlation between overall transparency and chlorophyll a levels in 2003. In contrast, transparency in Lough Arrow, a largely spring fed lake 2km north-west of Lough Key, has increased from <2m to 7m following the introduction of zebra mussels (C. Jennings, NWRFB, pers. comm.).

5.2.2 Chlorophyll *a*

Low chlorophyll *a* levels obtained during 2000-2003 cannot be attributed to limiting nutrients. The OECD (1982) model for eutrophication assumes that productivity predominantly occurs in the water column, i.e., the lake system functions via food and energy transfer through a pelagic food web. Once the zebra mussel became widely established in Lough Key, however, the system changed to a benthic (bottom) dominated system in which most of the productivity occurs in the benthic regime. The zebra mussels strip food resources from the water column, which are then reintroduced *via* faeces and pseudofaeces, as organic detritus directly to the benthic area. This involves extensive grazing on phytoplankton particles from 5-150 μm and some large mussels have been known to remove particles as large as 1.2mm (Horgan and Mills, 1997). In many studies high densities of mussels with high individual clearance rates (Fanslow *et al.*, 1995; Karatayev *et al*., 1997; Horgan and Mills, 1997; Kotta *et al*., 1998) have been attributed with the removal of phytoplankton and the subsequent reduction of chlorophyll *a* from various water-bodies. As the Lough Key chlorophyll levels remain consistently low, it appears that, with the exception of periodic seasonal blooms, the zebra mussel population is able to filter at a rate comparable to phytoplankton growth. The extent of this filtration in Lough Key will be dealt with in a later section of this discussion.

One major ecosystem impact of the increased transparency has been the increase in the growth of *Cladophora* and benthic macrophytes in response to greater light availability. This impact has been studied in both American and European waters (Skubinna *et al.,* 1995; Karatayev *et al*., 1997). Macrophytic biomass estimation techniques have been developed as biotic references for the Water Framework Directive (2000). Since the phytoplankton are being stripped from the water column by the zebra mussels, sampling of benthic algae and macrophytes rather than chlorophyll *a* could provide an alternative solution to assessing trophic status in *Dreissena* infested lakes.

5.2.3 Phosphorus

As mentioned previously the total phosphorus levels in Lough Key are not in tandem with the low chlorophyll *a* levels despite the filtering activity of the zebra mussel population, which removes total phosphorus both directly from the water column and also from the biomass of plankton consumed. Lough Key levels were consistently mesotrophic according to the OECD classification and suggest a constant input of phosphorus from the catchment area. It is presumed that a high percentage of this is entering *via* the Boyle River and that the major point source is the Boyle Sewage Treatment Plant. Statistical analysis of Boyle River total phosphorus and orthophosphate data upstream and downstream of the plant indicates that this indeed was the case.

The reassessment of the Toner (1979) Vollenweider model is useful in showing specific loadings for Lough Key because it incorporates mean depth, flushing rate and lake area. The model was slightly changed from the original because in this study, a new mean depth (4.5m) had been calculated from the bathymetric survey. Plotting the 2001-2003 annual loadings from Boyle Sewage Treatment Plant suggested that the phosphorus load in the first year of commissioning led to a mesotrophic status in the lake, while for the latter two years it was within oligotrophic levels. This should lead to long-term improvement in lake water quality if levels are kept within this margin.

Orthophosphate results for the project period were generally at their highest at spring sampling of each year, before uptake from algal/plant growth. The orthophosphate results for summer 2003 were very low (<5 μg/l) (Appendix 4). This is probably due to increased uptake by phytoplankton and macrophytes during the extremely good summer, as indicated by temperature datasets.

There is always the possibility that phosphorus may be released from resuspended sediment in the shallow and wind exposed areas of Lough Key, where zebra mussels are at their highest densities. Wind induced sediment resuspension occurs frequently in shallow areas (Sondergaard *et al.*, 1992). It is considered however, that this phosphorus may not be in a form readily available for use by phytoplankton (Nalepa *et al.*, 2000).

5.3 Phytoplankton and Cyanobacteria

Qualitative examinations of phytoplankton in lake samples can only give an estimation of the species which are dominant, numerous, present and absent. While this is not as accurate as actual cell counts, the data does provide a qualitative scale to assess any changes to the composition of phytoplankton in Lough Key. The drop in the level of chlorophyll *a* concentrations in the late 1990s is a clear indicator of the decline in levels of phytoplankton. This has been an international experience in waters where zebra mussels have been introduced (MacIssac *et al.*, 1995, Karatayev and Burlakova, 1997; Nalepa *et al.*, 1997; Maguire, 2003).

As stated in the results section, in terms of relative abundance of various taxa, there appears to have been no increase in *Microcystis* or any other cyanobacteria either during the course of the survey or relative to previous data (Bowman, 1998, 2000). These datasets also suggest that there are no definite trends in either increase or decrease of the relative densities of phytoplankton taxa during or before the project.

These results contradict the findings of Vanderploeg *et al.*, (1996) who suggest that zebra mussels selectively reject the cyanobacteria, *Microcystis*. Another study by Dionisio Pires (2004) showed that zebra mussels did not discriminate against cyanobacteria and indicated that they may even ingest them preferentially. Both of these studies were laboratory based. The situation is more complex in nature because *Microcystis* occurs mainly as colonies (0.5-1mm or much longer for *Microcystis aeruginosa* (John *et al.*, 2002), which float at the surface of the water and may not be available for consumption by zebra mussels. The *Microcystis* colonies that often appear during the summer/autumn blooms in Lough Key may or may not contain toxic strains. Neither the potential bioavailabilty issues of toxicity or accessibility appear to be favouring the dominance of *Microcystis* in the phytoplankton of Lough Key. As such the zebra mussel does not appear to have engineered any increased toxicity in algal blooms since the species arrived in Lough Key.

Evaluating the available datasets emphasises the need for regular monitoring of waters during the spring to autumn period to assess statistically valid means rather than occasional maximum levels of cyanobacteria and phytoplankton. Determination of bloom species is also important in case toxic *Microcystis* strains begin to dominate. Early identification of these strains would assist the public health management of leisure activities in Lough Key.

5.4 Zebra Mussels in Lough Key

Studies on larva, settlement and growth of zebra mussels during each project year gave indications of the following year's recruitment and survival.

5.4.1 Zebra Mussel Larval Stages

Increase in water temperatures in spring has been reported as the primary environmental factor explaining timing of reproduction of the zebra mussels, with 12^0C the minimum temperature allowing gonadal development, varying geographically with the rate of temperature increase (Garton and Haag, 1993; Sprung, 1989; Ram *et al.,* 1996). Water temperatures of 15^0C have been cited in many European studies, as the level at which larvae were first observed (Kachanova, 1966; Kirpichenko, 1964; Einsle, 1973; Stanczykowska, 1977; Karatayev, 1998). Peak responsiveness has been recorded at 20^0C. Seasonal changes in photoperiod and phytoplankton abundance may also influence spawning. In Lough Key spawning of zebra mussels commenced in May when temperatures reached 13^0C, with peak densities during the last two weeks of July and the first week of August, coinciding with periods of prolonged highest water temperatures and chlorophyll levels (Appendix 3).

Zebra mussel larvae are patchily/contagiously distributed within the lake. Even when densities are at their highest at one site, results may be very different for other sites within the lake (Appendix 5). This emphasizes the need for multiple site analysis, even within a small lake like Lough Key. Prevailing winds and currents have been suggested in other studies as explanations for this patchy distribution (Lewandowski, 1976; Hunter and Bailey, 1992; Martel, 1993). Results in this study indicate that peak densities were found at three separate sites in summers’ 2000-2004; it would not be possible to determine the role that weather conditions may have played without detailed meterological information. Veliger densities in this study fall within the wide range reported in the literature (Kirpichenko, 1964; Lewandowski, 1982b; Haag and Garton, 1992, Nalepa *et al.*, 1995).

The reason why the spawning cycle is prolonged over the summer and early autumn may be for one or more of several reasons:

a) Zebra mussels in principle are able to spawn with each individual releasing gametes over a period of six to eight weeks (Walz, 1978; Borcherding, 1992). So the same individuals may be spawning sequentially and this could result in bimodal patterns in size distribution analysis.

b) Separate age cohorts of zebra mussels may develop at different rates and smaller (1+) individuals may spawn later in the season than well developed (2+) zebra mussels. One year old zebra mussels are known to spawn in Irish waters (Juhel *et al.*, 2003).
c) Similar age cohorts may develop at different rates and spawn over the entire summer season. Smaller 1+ individuals become mature and spawn later in the season. In one study Borcherding (1991) observed this phenomenon and similar results have also been derived for marine species.

Seasonal size distribution patterns actually provide more useful information than larval densities, because it is possible to trace larval patterns (explained in the results section) over the summer period. As statistical analysis showed, there was variation in size distributions between different weeks during the sampling season indicating that veligers were growing and settling out as more were appearing at the smaller end of the spectrum (Appendix 6). Recovered juveniles as large as 840 μm probably represented re-suspended, settled individuals as in Martel, 1993. The presence of significant numbers of larva in late September 2003 was a new event for Lough Key and a definite new spawning event (recorded, September 2) must have been related to the high water temperatures during that summer. This could easily be explained by factors (a) or by (c) above.

Previously reported typical larval development time for Irish waters is between two to three weeks with settling out occurring from 200-370 μm (Lucy and Sullivan, 2000). The majority of veligers measured in samples over the three year period were between 100 and 130 μm - the numbers of veligers larger than this are always fewer. This may relate to early settlement, dispersal or is more likely due to high mortality rates prior to juvenile metamorphosis (Sprung, 1989). The relatively low representation of veligers smaller than 100 μm may have resulted from diagonal slippage through the net mesh.

5.4.2 Settlement

In some years settlement patterns showed highest levels, two to three weeks following peaks in larval densities. This was not always the case, in 2003 peak settlement rates occurred on August 19th, just one week after the highest density levels in larva had been recorded. It is not likely that development took place that rapidly and it is likely that the settlement reflects a relatively higher survival rate in larva. Large larva (>150 μm), close to settlement were relatively common in samples at Sites B, C and E on August 12th and 19th 2003.

Various factors, in particular mortality, make it difficult to relate larval abundance to settlement rates. Estimates of mortality rates (range 20-100%) indicate that most larval mortality (due to poor egg quality, predation or starvation) occurs late in the cycle during metamorphosis and settlement (Sprung, 1989). Apart from the peak week of larval density in 2003, seasonal results were relatively similar for larval densities in 2002 (Appendix 5). Fig 4.11 graphically demonstrates however, that settlement was much higher overall in 2003. This will be further demonstrated in the section on adult size distributions. Recruitment in 2002 was poorer than in any previous year, for reasons unknown (Appendix 7). Sprung (1989) estimated that mortality during the planktonic stage could be as high as 100 per cent in different years. Mortality (range 20-100%) could be due to a number of factors such as water turbulences (Rehmann *et al.*, 2003), predation by fish (Molloy *et al*., 1997), filtering by copepods or by adult *Dreissena* (MacIssac *et al*., 1991), bacterial infection, egg quality or starvation (Sprung, 1989). Although settlement was poor on 2002 plates, 0+ individuals were nevertheless well represented as the first age cohort in adult samples taken in early 2003 (Fig 4.13). Successful recruitment in 2003 may have been due to a decrease in development time related to the high water temperatures (degree-day related), which lead to an increased survival rate. Direct comparisons of larva and settlement within sites in Lough Key would be unscientific as they would not take the movement of larva by water currents into account. These inconsistencies in the abundance of developing life stages and in successful recruitment are in common with studies by Doka (1994), Nalepa (1997) and others.

5.4.3 Assessment of Habitat for Adult Zebra Mussels in Lough Key

Earlier survey work on Lough Key had established that in common with other Irish lakes, stoney substrates and *Anodonta* were the main substrates for adult zebra mussels in Lough Key (Lucy and Sullivan, 2001; Minchin *et al*., 2002a; Maguire, 2003). Aquatic plants were also found to be a substrate (Sullivan *et al*., 2002). The

Roxann™ and video surveys provided a remote system of mapping zebra mussel habitat. The simplification of these surveys into four main substrates was found to be a useful format for groundtruthing lake substrates.

In general the groundtruthing confirmed both the results of the Roxann survey and also the predominant use of hard substrates by zebra mussels, but it also some gave new significant results.

The discovery of zebra mussel clusters/druses on mud in transitional substrates is believed to be significant. Transition substrate areas are important for zebra mussel colonisation as they grade from densely colonised stoney substrate into mud. Transition zones could act as a stepping-stone for zebra mussel colonisation of Lough Key muddy substrates. Invasion of soft sediments has been widespread in Lake Erie, beyond 40m depth (Dermott and Munawar, 1993). Widespread colonisation of mud is considered unlikely, as outlined in the next section.

Groundtruthing in Lough Key revealed the presence of zebra mussels at 17.5m depth, although these were associated with rock it shows that there is food availability even in the deeper parts of the lake (maximum depth, 22m). In the Great Lakes, zebra mussels have been recorded from a number of depths and have been found as deep as 55 metres but the depth of maximum abundance there is usually 2-4 m (Mackie, 1996). Size distributions were similar at different depths indicating habitat suitability.

In addition to identifying substrates, video and transect survey work also targeted percentage composition of the various substrates in the littoral zone. This means that in addition to knowing substrate location and identification, one also has an idea of proportionality. This is important in context of the quantitative aspects of the survey, i.e., research at snorkel sites and also in the lake transect survey. The Roxann™ habitat map underestimates the quantity of categories 3 and 4 as the survey was unable to map areas <2m in depth, where a high proportion of zebra mussel biomass occurs. Estimating the percentage composition in video and transect work was carried out in order to input this information into the project.

5.4.4 Lake Substrates for Adult Zebra Mussels

The 1999 survey indicated that the three substrates used for settlement by zebra mussels in Lough Key were, in order of decreasing importance stone, *Anodonta* and aquatic plants (Lucy and Sullivan, 2001). This formed the basis for the snorkel survey work in the current project, which made it possible to examine zebra mussel biomass and size distributions at eight separate sites around the lake in both 2001 and 2003.

It might seem logical to assume that the poor settlement recorded in 2002 and the low numbers of 1+ individuals in size distributions recorded in summer 2003, might indicate a decline in the zebra mussel population. Visual analysis of percentage cover on stone had decreased at some sites (Appendix 8). Analysis of the zebra mussel biomass (on stone) at the seven stoney snorkel sites indicated however, that that there was no significant difference between 2001 and 2003. It thus appears that any decline in numbers of the 1+ cohort was made up for by the biomass of the larger 2+ cohort. As zebra mussel filtration is gauged by biomass, this measurement is considered to be more significant than examining actual numbers.

Size distributions sampled between 2000 and 2004 suggest that there is considerable annual variance in survival throughout the adult zebra mussel lifecycle. Although it is difficult to completely separate modes, the population appeared to shift from a dominance of 1+ cohort (2000), to a mixed 1+/2+ (2001) and then to a 2+ cohort (2003). The reduction in numbers of smaller zebra mussels seemed to suggest that a population decline might follow. This has been the general pattern that has emerged from some long-term studies on zebra mussels in Europe (reviewed in Karatayev *et al.*, 1997). Such a decline has not been evident in Lough Key. High settlement in summer 2003 resulted in the recruitment of large numbers of zebra mussels, dominating the size distributions in early 2004.

Density dependant processes etc may balance the successful recruitment and survival of the species and may cause fluctuations in populations (Ramcharan *et al.*, 1992; Karatayev *et al.*, 1998). During the time period of this project the zebra mussel population appeared to be stable in terms of biomass; the lake appears to be maintaining an equilibrium carrying capacity for this species. The degree to which populations irregularly fluctuate varies widely among European lakes; in some it varies by no more than 15 percent over periods of 5-10 years (Ramcharan *et al*., 1992) and this may be the case for Lough Key.

In common with many other lakes elsewhere, the two main density dependant factors involved in the abundance of zebra mussels in Lough Key are availability of suitable substrate and sufficient food source (Lucy and Sullivan, 2001). As camera work and snorkel surveys indicated that stone substrate throughout the lake was not fully colonised by zebra mussels (< 100%) it seems likely that food availability is the major limiting factor to population increases in Lough Key.

In terms of extrinsic factors, zebra mussel predation has been reviewed internationally (Molloy *et al.,* 1997). Some of the fish (*Anguilla anguilla*, eel; *Rutilus rutilus*, roach; *Abramis brama*, bream; *Scardinius erythropthalmus*, rudd) and bird species (*Anas platyrhynchos*, mallard; *Aythya fuligula*, tufted duck; *Bucephula clangula*, golden eye) which prey on zebra mussels are present in the Shannon. Mallard have been observed feeding on zebra mussels in Lough Key (pers. Obs.) but any predation research was beyond the scope of this project. There were no bare 'grazed' patches evident in camera or snorkel survey work. Predation could occur however on larval stages (Van der Velde *et al.*, 1994) and this may contribute to reduced survival in the early stages. The consistency in zebra mussel biomass seems to show that predators were not availing of this new introduced dietary item in sufficient quantities to create any significant negative impact in populations in Lough Key.

Colonisation of macrophytes has been well recorded in the European literature (Sozka, 1975; Shapkarev and Angelovski, 1978; Lewandowski, 1982b, 1983, 1991; Karatayev and Burlakova, 1995a; Grigorovich and Babko, 1997). In Lough Key, the initial high zebra mussel settlement on macrophytes seems to have been a function of the invasive stages of colonisation. The early 'corn on the cob' effect on old *Phragmites* stems may relate to relatively high rates of successful settlement from 1998 to 2000 (Lucy (unpublished), Lucy and Sullivan, 2001) and subsequent high survival of juveniles. Unlike annual macrophytes, *Phragmites* stems do not die back after the year's growth and instead last up to three years, the life span of most zebra mussels. All age cohorts of zebra mussels were represented on these 2001 stems.

The rhizoids of this plant and those of *Nuphar lutea* and *Equisetum fluviatile* also survive year round and video surveys showed that zebra mussels use these plant structures as permanent substrates. The extreme decline in biomass on old *Phragmites* stems was most noticeable at snorkel site 1, a site with a soft substrate where *Phragmites* and *Anodonta* shells provide the only settlement substrate for zebra mussels. This decline does not represent a large decrease in the zebra mussel population as previous work has shown that the overall biomass on plants even during the early phase was estimated at <2% and is limited to the outer 1m periphery of reed-beds. Grigorovich and Babko (1997) also noted the baffling effect, which limits settlement to the outer 1m of reed beds.

The other plants noted in the survey only serve as transient substrates and die back in the autumn with young of the year zebra mussels attached. Unless these mussels can find a suitable hard substrate to continue their life cycle, they are unlikely to survive. There is also a possibility of zebra mussel dispersal via drifting vegetation (Horvarth *et al.*, 1997; Sullivan *et al.*, 2003). The high rate of settlement in 2003 may result in temporary increased usage of plants as substrates, but for reasons outlined above, this is unlikely to be significant.

Impacts of the zebra mussel on native bivalves has been researched extensively both in Europe and North America (Lewandowski, 1976; Ricciardi *et al.*, 1995; Schloesser *et al.*, 1996; Karatayev *et al.*, 1997). In North America and Europe all native unionid (bivalve) species that occur sympatrically with zebra mussels have been infested by them with an average of four years for a 90 per cent decline in unionid population (Ricciardi *et al.,* 1995; Schloesser *et al*., 1996; Martel *et al*., 2001).

The very high initial rates of settlement on *Anodonta* is a widespread phenomenon as the unionid family form a preferential substrate for zebra mussels (Lewandowski, 1976; Mackie and Schloesser, 1996) and often provide the only suitable substrate in soft sediments. This has lead to their extinction in the Lough Key as *Anodonta* has no evolutionary burying mechanism to deal with zebra mussel colonisation. This type of mass mortality is well documented in the literature.

In Lough Key, the initial high zebra mussel settlement on *Anodonta* also seems to have been a function of the invasive stages of colonisation as reviewed elsewhere in Karatayev *et al.*, 2002. The decline in usage of this substrate is not just related to the decline in settlement rates. It also reflects the unavailability of this substrate due to sinking of the burdened shells into the soft muddy substrate. Byssal plaques present on some of these partially buried shells indicate that settlement took place in the early years of invasion. Presuming that food supply is the limiting factor in the lake, any loose druses attached to shells are unlikely to form new extensive colonies on the muddy substrate in the future, given the availability of preferential stoney substrate. Availability of hard substrate also signifies that any eventual loss of *Anodonta* shells for settlement is unlikely to impact on zebra mussel population size in Lough Key.

Anodonta formed a significant substrate for zebra mussels in 1999 (37% estimate) (Lucy and Sullivan, 2000). Implications for survival were indicated at the time as only 50 per cent of *Anodonta* sampled at that time were alive; from 2000 onwards no live specimens have been found. The complete demise of this native bivalve mollusc is the most direct ecological impact caused by zebra mussels in Lough Key. Shannon surveys indicate that the extirpation of *Anodonta* is widespread throughout the Shannon navigation (Minchin *et al.*, 2002b). This is a clear cut example of how an invasive species can impact on native biodiversity and there may be a case for *Anodonta* joining the pearl mussel (*Margaritifera margaritifera*) on the list of protected species in Ireland (EPA, 2004).

5.4.5 Transect Survey Results

Methodology for estimating numbers of zebra mussels was more sophisticated and detailed in this project than in the 1999 study. The total number of zebra mussels in Lough Key was estimated in this project at 34 billion with a rounded total biomass of 4.4×10^6 kg. The greatest numbers of zebra mussels occurred in the first three metres of depth (Appendix 9) and this relates directly with availability of suitable substrate (Categories 3 and 4). Although this number far exceeds the previous 6 billion estimated in 1999, the difference in numbers is believed to be mainly due to a difference in methodology. The snorkel survey work suggests that the population remained relatively stable from 2001-2003. Total number is a useful tool in the explanation of how an invasive species can multiply exponentially in a short period of years. In terms of biological impacts, biomass is a more meaningful parameter which can be used to assess filtration and consequently related to trophic status in the lake.

5.4.6 Filtration Capacity of Zebra Mussels in Lough Key

From 10^0C upwards zebra mussels have been shown to filter at their peak capacity up to temperatures of at least 20^0C (Reeders and Bij de Vaate, 1990; Fanslow *et al*., 1995). In Lough Key water temperatures exceed 10^0C for seven months of the year (March-November) of the year as shown by the temperature data. Zebra mussels were observed to be open during all seasonal video surveys.

The filtration rate as calculated assumes maximum filtration rates and may be excessive for periods of lower water temperature. As many of the zebra mussels in the lake are found in dense druses, it is likely that the filtration capacity of many larger zebra mussels (2+) located towards the centre of a druse may be compromised by the surrounding settlement of younger (0-1+) zebra mussels. Laboratory experiments on clearance rates and filtration activity of different size classes of zebra mussels in the literature researched for this report have not in general taken into account this 3-D factor of the druse and the location of zebra mussels within. Tuchman *et al*. (2004) however, found ingestion rates of individual mussels located at the surface to exceed those at the bottom of a 6cm thick colony by up to 75%. The filtration rate calculated also only takes into account filtration by zebra mussels >1mm; it is likely that veligers and juvenile zebra mussels also contribute substantially to the overall filtration of Lough Key.

The 10 day lake filtration time calculated for Lough Key is considerably shorter than the overturn rate of 58 days (0.16 year*)*. i.e. the total natural replacement of the lake water volume. On this basis alone the Vollenweider model and OECD classification seem too simplistic to assess the trophic status of Lough Key.

As the highest biomass of zebra mussels are found on hard substrates near shores of Lough Key, maximum filtration occurs in these areas and not in the open waters of the lake. So how can it be determined whether the water is well mixed? There was very little difference in EPA parameter values (e.g temperature, dissolved oxygen, chlorophyll *a*, total phosphate) at different depths during the fair summer of 2003;

EPA stations B, D and E (surface and 6m depths) and at station C (surface and 18m depth) showed very similar results (Appendix 4). Although a slight thermocline has been observed at station C during this study and in other monitoring (Bowman, 2000), this is believed to be a transient phenomenon. Results between lake sites were also similar in most of the project and EPA datasets throughout 2001-2003, indicated that the water in Lough Key was well mixed in both pelagic and profundal layers. In addition the similarity of size distributions between zebra mussels at 0-1m and 12-13m depth indicated that food was available in the aphotic, profundal zone due to adequate mixing of water. The probable scenario is that water in near shore areas of high zebra mussel density is simultaneously mixed and filtered, except on extremely calm days when it may be filtered to a high degree before it is overturned by wind induced currents.

5.5 Potential Links Between Zebra Mussel Populations and Nutrient Levels in Lough Key

The total phosphorus results show that loadings to the lake from Boyle Sewage Treatment Plant had been reduced between 2001 and 2003. There was also a drop in total phosphorus levels in Lough Key. It is not possible however to separate the nutrient impact of the new STP from that due to zebra mussel filtering. The Vollenweider model postulates that even without zebra mussels, total phosphorus loadings since 2002 are within acceptable levels for the lake. This dual reduction has not as yet resulted in phosphorus levels becoming limited. This is evident from the increase in benthic algae and macrophytes. As the zebra mussel population remained stable during the project period it suggests that phytoplankton were still being produced in abundance, but are immediately stripped from the water column by filtering activity.

As of 2004, seasonal algal blooms were still occuring either because the algae are inaccessible (due to size or flotation) or because the zebra mussels are unable to process the phytoplankton during intense periods of algal growth. This emphasises the need for regular monitoring of waters during the spring to autumn period to assess statistically valid means rather than occasional maximum levels. Determination of species in blooms is also important in case a switch to the dominance in *Microcystis* species (possibly toxic strains) occurs with time – this is an important public health issue.

If in subsequent years the total phosphorus levels diminish due to the dual action of the treatment plant and the zebra mussels, it is entirely possible that the zebra mussel population will be reduced in size. This was not the case during the course of the project and such an outcome could only be established by a long term monitoring programme.

5.6 Zebra Mussels and the Water Framework Directive

Invasive species are not directly mentioned in the Water Framework Directive 2000 (WFD) but could be considered as 'anthropogenic impacts' on the biological elements listed in Annex V (Boon, 2003). The WFD is a complex directive, which involves classification according to biological, physico/chemical and hydromorphological status (Littlejohn *et al*., 2002). The colonisation of zebra mussels in Shannon lakes has resulted in many WFD related changes. Table 5.1 outlines the elements within each category, which have been highlighted in this project. Zebra mussels have also been shown to impact on diversity and biomass of various macroinvertebrate and fish species due to the switch they create from pelagic to benthic systems (Dermott and Kerec, 1997; Karatayev *et al*., 1997; Beekey *et al*., 2004).

Table 5.1 Water Framework Directive elements, changed by zebra mussel colonisation of Lough Key

Biological	**Physico/Chemical**	**Hydromorphological**
Anodonta	Transparency	Substrate changes due to high densities on stone
Chlorophyll *a*	Total Phosphorus	
Phytoplankton		
Macrophytes		
Phytobenthos		

As zebra mussels are an introduced species that create changes to the biology, physicochemistry and hydromorphology of Lough Key it is very difficult to consider whether the lake can achieve good ecological quality status according to the Water Framework Directive. There may also be significant changes to the lake between this survey period and 2015, by which time good quality should be achieved according to the Water Framework Directive.

Chapter 6. Conclusions

- Lough Key remains firmly within mesotrophic levels as total phosphorus remains within those trophic limits (10-35 mg/m^3). Neither the decrease in loadings from Boyle Sewage Treatment Plant nor impacts caused by the zebra mussel population in the lake have reduced these levels sufficiently to achieve oligotrophic status.
- Low chlorophyll *a* levels and high transparency are directly related to the filtration capacity of the zebra mussel population, which can filter the entire lake in an estimated 10 days. Seasonal algal blooms persist but have not shown any consequent increase in *Microcystis* abundance. No toxic strains were present in algal blooms during the course of this project. Increased benthic macrophytes and alga are a direct response to resultant increased transparency and continued bioavailability of nutrients for growth.
- Zebra mussels are mainly found on stone and rock in 3m depth or less, with small numbers found on occasional rocky areas at greater depths. Hard substrate was often less than 100 percent colonised, implying that food and not space is the density-dependant limiting factor for zebra mussels in Lough Key. There was no sign of colonisation developing in the extensive areas of mud substrate.
- The most direct impact of zebra mussel colonisation in Lough Key has been the extirpation of the native duck mussel *Anodonta anatina.* By 2003 the heavily-burdened, sinking *Anodonta* shells were becoming less available as zebra mussel substrates.
- The total biomass of zebra mussels in the lake is 4.4 x 10^6 kg, with a total number of 34 billion. Biomass remained consistent between 2001 and 2003. Variation in spawning and settlement patterns did occur, with some years showing more successful recruitment than others. As most zebra mussels survive and spawn over two summers, the data suggests that such imbalances may be evened out over several age cohorts resulting in a similar biomass.
- Zebra mussels create problems in classifying lakes according to the Water Framework Directive for two reasons. Firstly, they are aquatic aliens and thus regarded as a biological pressure and impact, and secondly they cause direct

changes to biological, physical/chemical and hydromorphological elements relating to this directive.

References

Ackerman, J.D., Blair, S., Nichols, S.J. and Claudi, R., 1994. A review of the early life history of zebra mussels (*Dreissena polymorpha*): comparisons with marine bivalves. Canadian Journal of Zoology **72**, 1169-1177.

Astanei, I., Gosling, E., Wilson, J. and Powell, E., 2005. Genetic variability and phylogeography of the invasive zebra mussel, *Dreissena polymorpha* (Pallas). *Molecular Ecology* **14**(6), 1655-1666.

Bastviken, D.T.E., Caraco, N.F. and Cole, J.C., 1998. Experimental measurement of zebra mussel (*Dreissena polymorpha*) impacts on phytoplankton community composition. *Freshwater Biology* **39**, 375-386.

Beekey, M.A., McCabe, D.J. and Marsden, J.E., 2004. Zebra mussel colonisation of soft sediments facilitates invertebrate communities. *Freshwater Biology* **49**, 535-545.

Berkman, P.A., Haltuch, M.A. and Tichich, E., 1998. Zebra mussels invade Lake Erie muds. *Nature* **393**: 27-28.

Boon, P., 2003. Alien species and the water framework directive. Ecological change in Lough Erne; Proceedings of Queens University workshop, Co. Fermanagh.

Borcherding, J., 1991. The annual reproductive cycle of the freshwater mussel *Dreissena polymorpha* Pallas in lakes. *Oecologia* **87**, 208-218

Borcherding, J., 1992. Morphometric changes in relation to the annual reproductive cycle in *Dreissena polymorpha* – a prerequisite for biomonitoring studies with zebra mussels. *In*: Neumann, D. and Jenner, H.A. (eds) *The zebra mussel Dreissena polymorpha*. Gustav Fischer Verlag, New York. pp 87-99.

Bowman, J.J., 1998. *River Shannon lake water quality monitoring 1995 to 1997*. EPA, Wexford. 74pp.

Bowman, J.J., 2000. *River Shannon lakewater quality monitoring 1998-1999*. EPA, Wexford. 78pp.

Chase, M.E. and Bailey, R.C., 1999. The ecology of the zebra mussel (*Dreissena polymorpha*) in the Lower Great Lakes of North America. *Journal of the Great Lakes Research*. **25**, 107-121.

Chorus, I. and Bartram, J., 1999. *Toxic cyanobacteria in water: a guide to their public health consequences, monitoring and management*. E and FN Spon, London.

Conn, D.B., Lutz, R.A., Ya-Ping, H and Kennedy, V.S., 1993. *Guide to the identification of larval and postlarval stages of zebra mussels Dreissena spp. and the dark false mussel, Mytilopsis leucophaeata*. New York Sea Grant, New York.

Council of the European Communities, 2000. Directive 2000/60/EC of the European parliament and of the council of 23 October 2000 establishing a framework for community action in the field of water policy. *Official Journal of the European Communities* No L 327. 71 pp.

Commons, E., 2000. *The zebra mussel in Lough Key - veliger research 1999*. Unpublished BSc thesis. Institute of Technology, Sligo.

Dermott, R. and Munawar, M., 1993. Invasion of Lake Erie offshore sediments by *Dreissena*, and its ecological implications. *Canadian Journal of Fisheries and Aquatic Science* **50**, 2298-2304.

Dermott, R. and Kerec, D., 1997. Changes to the deepwater benthos of eastern Lake Erie since the invasion of Dreissena:1979-1993. *Canadian Journal of Fisheries and Aquatic Science* **54**, 922-930.

Dionisio Pires, L.M., Jonker, R.R., Van Donk, E. and Laanbroek, H.J., 2004. Selective grazing by adults and larvae of the zebra mussel (*Dreissena polymorpha*): application of flow cytometry to natural seston. *Freshwater Biology* **49**, 116-126.

Doka, S.E. and Mackie, G.L., 1993. Settlement rates of Dreissena polymorpha veligers on an artificial substrate in relation to biotic and abiotic factors in Lake Erie. Proceedings of *Third International Zebra Mussel Conference*, Toronto.

Duggan, S., 2001. *An investigation of Dreissena polymorpha in Lough Key*. Unpublished BSc thesis. Institute of Technology, Sligo.

Einsle, U., 1973. Zur horizontal und vertikalverteilung der larven von *Dreissena polymorpha* Pallas im pelagial des Bodensee-Obersees (1971). *Gwf-wasser/abwasser* **114**, 27-30.

EPA (Environmental Protection Agency), 2001. Parameters of Water Quality Interpretation and Standards. EPA, Wexford. 143pp.

EPA (Environmental Protection Agency), 2002. Water quality in Ireland. EPA, Wexford. 128pp.

EPA (Environmental Protection Agency), 2004. Ireland’s Environment. EPA, Wexford. 316pp.

Fanslow, D.L., Nalepa, T.F. and Lang, G.A., 1995. Filtration rates of the zebra mussel (*Dreissena polymorpha*) on natural seston from Saginaw Bay, Lake Huron. *Journal of Great Lakes Research* **21(4)**, 489-500.

Garton, D.W. and Haag, W.R., 1993. Seasonal reproductive cycles and settlement patterns of *Dreissena polymorpha* in western Lake Erie. *In*: Nalepa, T.F. and Schloesser, D.W. (eds) *Zebra mussels, Biology, Impacts and Control*. Lewis Publishers. Florida. pp 111-128.

Grigorovich, I.A., Babko, R.V. 1997. Sessile invertebrates in beds of aquatic macrophytes. *In* D'Itri, F. (ed.) *Zebra mussels and aquatic nuisance species*. Ann Arbor Press. Michigan.

Haag, W.R. and Garton, D.W., 1992. Synchronous spawning in a recently established population of the zebra mussel, *Dreissena polymorpha*, in western Lake Erie, USA. *Hydrobiologia* **234**, 103-110.

Hebert, P.D.N., Wilson, C.C., Murdoch, M.H., and Lazar, R., 1991. Demography and ecological impacts of the invading mollusc, *Dreissena polymorpha*. *Canadian Journal of Fisheries and Aquatic Science* **69**, 405-409.

Hillbricht-Ilkowska A., and Stanczykowska A. 1969. The production and standing crop of planctonic larvae of *Dreissena polymorpha* (Pall.) in two Mazurian lakes. *Polskie Archiwum. Hydrobiol*ogii, **16 (29)**, 193-203.

Holland, R.E., 1993. Changes in planktonic diatoms and water transparency in Hatchery Bay, Bass Island area, Western Lake Erie since the establishment of the zebra mussel. *Journal of Great Lakes Research* **19(3)**, 617-624.

Holland, R.E., Johengen, T.H. and Beeton, A.M., 1994. Trends in nutrient concentrations in Hatchery Bay, western Lake Erie, before and after *Dreissena polymorpha*. *Canadian Journal of Fisheries and Aquatic Science* **52**, 1202-1209.

Horgan, M.J. and Mills, E.L., 1997. Clearance rates and filtering activity of zebra mussel (*Dreissena polymorpha*): implications for freshwater lakes. *Canadian Journal of Fisheries and Aquatic Science* **54**: 249-255

Horvarth, T.G., Lamberti, G.A., Lodge, D.M. & Perry, W.P., 1996. Zebra mussel dispersal in lake stream systems: source-sink dynamics? *Journal of the North American Benthologists' Society* **11**, 341-349.

Howitt, D. and Cramer, D., 2003. *A guide to computing statistics with SPSS11 for windows.* Revised edition. Prentice Hall, Harlow.

Hunter, R.D. & Bailey, J.F., 1992. *Dreissena polymorpha* (zebra mussel): colonisation of soft substrata and some effects on Unionid bivalves. *Nautilus* **106**: 60-67.

Jack, J.D. and Thorp, J.H., 2000. Effects of the benthic suspension feeder *Dreissena polymorpha* on zooplankton in a large river. *Freshwater Biology* **44**, 569-579.

Johengen, T.H., Nalepa, T.F., Fahnenstiel, G.L. and Goudy, G., 1995. Nutrient changes in Saginaw Bay, Lake Huron, after the establishment of the zebra mussel (*Dreissena polymorpha*). *Journal of Great Lakes Research* **21(4)**, 449-464.

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

Johnson, L and Padilla, D.K., 1996. Geographic spread of exotic species: ecological lessons and opportunities from the invasion of the zebra mussel, *Dreissena polymorpha*. *Biological Conservation* **78**, 23-33.

Juhel, G., Culloty, S.C., O'Riordan, R.M., O' Connor, J., De Faoite, L. and McNamara, R., 2003. A histological study of the gametogenic cycle of the freshwater mussel *Dreissena polymorpha* (Pallas, 1771) in Lough Derg, Ireland. *Journal of Molluscan Studies* **69**, 365-373.

Kachanova, A.A., 1961. Some data on the reproduction of *Dreissena polymorpha* Pallas in Uchinsk reservoir. *Trudy Vsesoyuznogo Gidrobiologicheskogo Obschestva* **11**, 117-121 (In Russian).

Kirpichenko, M. J., 1964. Phenology, abundance and growth of *Dreissena* larvae in the Kujbysev reservoir. In: Sbornik (ed.) *Biologija Drejsseny I borba z nej*. Izat Nauka, Moskva.

Karatayev, A.Y., Lyakhnovich,V.P. and Reznichenko, O.G., 1990. Quantitative study of the density, biomass and abundance dynamic. In:Shkorbatov, G.L. and Starobogatov, Y.I. (eds.) *Methods for study of bivalvian molluscs*. *Trudy Zoologicheskogo Instituta* **29**, 172-178 (in Russian).

Karatayev, A.Y., and Burlakova, L.E., 1993. The filtering activity of *Dreissena* and its influence on the trophic stucture of planktonic and benthic invertebrates.*In*: *Proceedings on the fourth international conference on the project:species and its productivity within their range*. Gidromiteoizdat Press, St Petersburg (in Russian), pp 211-213.

Karatayev, A.Y. and Burlakova, L.E., 1995. The role of *Dreissena* in lake ecosystems. *Russian Journal of Ecology* **26**, 207-211.

Karatayev, A.Y., Burlakova, L.E. and Padilla, D.K., 1997. The effects of *Dreissena polymorpha* invasion on aquatic communities in eastern Europe. *Journal of Shellfish Research* **16(1)**, 187-203.

Karatayev, A.Y., Burlakova, L.E. and Padilla, D.K., 1998. Physical factors that limit the distribution and abundance of *Dreissena polymorpha* (Pall.). *Journal of Shellfish Research* **17(4)**, 1219-1235.

Karatayev, A.Y., Burlakova, L.E. and Padilla, D.K., 2002. Impacts of zebra mussels on aquatic communities and their role as ecosystem engineers. In: Leppakowski, E., Gollasch, S. and Olenin, S. (eds.) *Invasive aquatic species of Europe. Distribution, impacts and management*. Kluwer Academic Publishers, Dordrecht. Pp 433-447.

Kondratiev, G.P., 1962. Features of filtration of *Dreissena polymorpha* Pallas. *Trudy Saratovskogo Otdeleniya Vsesoyuznogo Nauchno-issledovatel'skogo Instituta Ozernogo i Rechnogo Rybnogo Khozyajstva.* **7,** 280-283 (in Russian).

Kotta, J., Orav, H. and Kotta, I., 1998. Distribution and filtration activity of the zebra mussel, *Dreissena polymorpha*, in the Gulf of Riga and the Gulf of Finland. *Proceedings of the Estonian Academy of Science, Biology and Ecology* **47**, 32-41.

Lewandowski, K., 1976. Long-term changes in the fauna of family Unionidae bivalves in the Mikolajskie Lake. *Ekologia Pol*ska **39**, 265-272.

Lewandowski, K., 1982a. The role of early developmental stages in the dynamics of *Dreissena polymorpha* (Pall.) (Bivalvia) populations in lakes 1. Occurrence of larvae in the plankton. *Ekologia Polska* **30 (1-2)**, 81-109.

Lewandowski, K., 1982b. The role of early developmental stages in the dynamics of *Dreissena polymorpha* (Pall.) (Bivalvia) populations in lakes 11. Settling of larvae and the dynamics of settled individuals. *Ekologia Polska* **30 (3-4)**, 223-286.

Lewandowski, K., 1983. Occurrence and filtration capacity of young plant dwelling Dreissena polymorpha (Pall.) in Majcz Wielki Lake. *Polskie Archiwum. Hydrobiol*ogii, **30(3)**, 255-262.

Lewandowski, K., 1991. The occurrence of Dreissena polymorpha (Pall.) in some mesotrophic lakes of the Masurian Lakeland. *Ekologia Polska,* **39(2)**, 273-286.

Littlejohn, C., Nixon, S., Casazza, G., Fabiani, C., Premazzi, G., Heinonen, P., Ferguson, A. and Pollard, P., 2002. Guidance on monitoring for the water framework directive, final draft. Working group 2.7, monitoring.

Lohan, J., 2004. *An investigation of the early life stages of the zebra mussel, dreissena polymorpha in Lough Key, 2003*. Unpublished BSc thesis. Institute of Technology, Sligo.

Lucy, F. and Sullivan, M., 2001. *The investigation of an invasive species, the zebra mussel Dreissena polymorpha in Lough Key, Co Roscommon, 1999*. Desktop Study no. 13. Irish EPA, Wexford.

Lvova, A.A., *1977. The ecology of Dreissena polymorpha in Uchinskoe reservoir*. Candidate dissertation, Moscow University.

Mackie, G.L., Gibbons, W.N., Muncaster, B.W. and Gray, I.M., 1989. The zebra mussel, *Dreissena polymorpha*: a synthesis of European experiences and a preview for North America. *Report prepared for Water Resources Branch, Great Lakes Section*. Ontario.

Mackie, G.L., 1991. Biology of the exotic zebra mussel, *Dreissena polymorpha*, in relation to native bivalves and its potential impact in Lake St. Clair. *Hydrobiologia* **219**, 251-268.

Mackie, G.L. and Schloesser, D.W., 1996. Comparative biology of zebra mussels in Europe and North America: an overview. *American Zoologist*. **36**, 234-248.

MacIssac, H., Sprules, W.G. and Leach, J.H., 1991. Ingestion of small-bodied zooplankton by zebra mussels (*Dreissena polymorpha*): can cannabalism on larvae influence population dynamics? *Canadian Journal of Fisheries and Aquatic Science* **48**, 2051-2060.

MacIssac, H.J., Lonnee, C.J. and Leach, J.H., 1995. Suppression of microzooplankton by zebra mussels: importance of mussel size. *Freshwater Biology* **34**, 379-387.

Maguire, C.M., Roberts, D. and Rosell, R.S., 2003. The ecological impacts of a zebra mussel invasion in a large Irish lake, Lough Erne: a typical European experience? *Aquatic Invaders* **14 (1)**, 10-18.

Marsden, J.E., 1992. Standard protocols for monitoring and sampling zebra mussels. *Illinois Natural History Survey, Biological Notes* 138. 38pp.

Marshall, A., 2002. *An investigation of Dreissena polymorpha in Lough Key*. Unpublished BSc thesis. Institute of Technology, Sligo.

Martel, A., 1993. dispersal and recruitment of zebra mussel (*Dreissena polymorpha*) in a nearshore area in West-central Lake Erie: the significance of postmetamorphic drifting. *Canadian Journal of Fisheries and Aquatic Science* **50**, 3-12.

Martel, A.L., Pathy, D.A., Madill, J.B., Renaud, C.B., Dean, S.L. and Kerr, S.J., 2001. Decline and regional extirpation of freshwater mussels (Unionidae) in a small river system invaded by *Dreissena polymorpha*: the Rideau River, 1993-2000. *Canadian Journal of Zoology* **12**, 2181-2191.

McCarthy, T. K., Fitzgerald, J. and O'Connor, W., 1998. The ocurrence of the zebra mussel *Dreissena polymorpha* (Pallas. 1771), an introduced biofouling freshwater bivalve in Ireland. *Irish Naturalists' Journal* **25(11/12)**, 413-415.

McGarrigle, M.C., Bowman, J.J., Clabby, K.J., Lucey, J., Cunningham, M., MacCárthaigh, M., Keegan, M., Cantrell, B., Lehane, M., Clenaghan, C. and Toner, P.F. 2002. *Water Quality in Ireland 1998-2000*. EPA, Wexford.

Metcalf, J.S. and Codd, G.A., 2004. Cyanobacterial toxins in the water environment. A review of current knowledge. Foundation for Water Research FR/R0009, Bucks. 36pp.

Minchin, D. and Moriarty, C., 1998. Zebra mussels in Ireland. *Fisheries Leaflet No 177*, Marine Institute. 11pp.

Minchin, D. Lucy, F. & Sullivan, M. 2002a. Zebra mussel: Impacts and Spread. In: Leppakoski, E., Gollasch S. and Olenin, S. (eds) Invasive Aquatic Species of Europe: Distribution, Impacts and Spread. Kluwer Press, Dordrecht. pp 135-146.

Minchin, D., Lucy, F. and Sullivan, M., 2002b. Monitoring of zebra mussels in the Shannon-Boyle navigation, other navigable regions and principal Irish lakes, 2000 and 2001. *Marine Environment and Health Series, No. 5.* Marine Institute, Dublin.

Minchin, D., Lucy, F., and Sullivan, M., 2003. Monitoring of zebra mussels in the Shannon-Boyle catchment and their expansion to midland lakes. *Report to the Marine Institute, Dublin.* 22 pp.

Molloy, D.P., Karatayev, A.Y., Burlakova, L.E., Kurandina, D.P. and Laruelle, F., 1997. Natural enemies of zebra mussels: predators, parasites and ecological competitors. *Reviews in Fisheries Science*. **5(1)**: 27-97.

Nalepa,T.F., Wojik, J.A., Fanslow, D.L. and Lang, G.A., 1995. Initial colonisation of the zebra mussel (*Dreissena polymorpha*) in Saginaw Bay, Lake Huron: population recruitment, density and size structure. *Journal of Great Lakes Research* **21(4)**, 417-434.

Nalepa, T.F., Fahnenstiel, G.L. and Johengen, T.H. 1999. Impacts of the zebra mussel on water quality: a case study in Saginaw Bay, Lake Huron. In: Claudi, R. (ed.)

Nonindigenous freshwater organisms: vectors, biology and impacts. CRC Press, Florida. pp 255-271.

New York Sea Grant, 2003. North American range of the zebra mussel as of December, 2003. *Aquatic Invaders* **14(4)**, 12-13.

Nichols, S.J., 1996. Variations in the reproductive cycle of *Dreissena polymorpha* in Europe, Russia and North America. American Zoologist **36**, 311-325.

Ni Chonmhara, E. 1999. *The zebra mussel in Lough Key, 1998-1999*. Unpublished BSc thesis. Institute of Technology, Sligo.

OECD (Organisation for Economic Cooperation and Development), 1982. *Eutrophication of waters, monitoring, assessment and control*. OECD, Paris

O' Mahony, K., 2003. *An investigation of Dreissena polymorpha in Lough Key*. Unpublished BSc thesis. Institute of Technology, Sligo.

Pollux, B., Minchin, D., Van der Velde, G., Van Alen, T., Van der Staay, S and Hackstein, J., 2003. Zebra mussels in Ireland (*Dreissena polymorpha*), AFLP-fingerprinting and boat traffic both indicate an origin from Britain. *Freshwater Biology* **48**, 1127-1139.

Ram, J.L., Fong, P.P. and Garton, D., 1996. Physiological aspects of zebra mussel reproduction: maturation, spawning and fertilization. *American Zoologist* **36**, 326-338.

Ramcharan, C.W., Padilla, D.K. and Dodson, S.I., 1992. A multivariate model for predicting population fluctuations of Dreissena polymorpha in North American lakes. *Canadian Journal of Fisheries and Aquatic Science* **49**, 150-158.

Reeders, H.H. and Bij de Vaate, A., 1990. Zebra mussels (*Dreissena polymorpha*): a new perspective for water quality management. *Hydrobiologia* **200/201**, 437-450.

Rehmann, C.R., Stoeckel, J.A. and Schneider, D.W., 2003. Effect of turbulence on the mortality of zebra mussel veligers. *Canadian Journal of Zoology* **81**, 1063-1069.

Ricciardi, A., Whoriskey, F.G. and Rasmussen, J.B., 1995. Predicting the intensity and impact of *Dreissena* infestation on native unionid bivalves from *Dreissena* field density. *Canadian Journal of Fisheries and Aquatic Science* **52**, 1449-1461.

Ricciardi, A., Neves, R.J. and Rasmussen, J.B., 1998. Impending extinctions of North American freshwater mussels following the zebra mussel (*Dreissena polymorpha*) invasion. *Journal of Animal Ecology* **67**, 613-619.

Rosell, R., Maguire, C.M. and McCarthy, T.K., 1999. First settlement of zebra mussels *Dreissena polymorpha* in the Erne system, Co Fermanagh. Northern

Ireland. *Biology and Environment: Proceedings of the Royal Irish Academy* **98B(3)**, 191-193.

Schloesser, D. & Nalepa, T. & Mackie, G.L. 1996. Zebra mussel infestation of unionid bivalves (Unionidae) in North America. *American Zoologist* **36**, 300-310.

Shapkarev, J.A. and Angelovski, P.J., 1978. Population dynamics of *Dreissena polymorpha* on *Phragmites communis* from Dojran Lake. *Godisen Zbornik* **31**, 29-51.

Skelly, A., 2000. *The impact of the zebra mussel on Anodonta populations in Lough Key*. Unpublished BSc thesis. Institute of Technology, Sligo.

Skubinna, J.P., Coon, T.G. and Batterson, T.R., 1995. Increased abundance and depth of submersed macrophytes in response to decreased turbidity in Saginaw Bay, Lake Huron. *Journal of Great Lakes Research* **21(4)**, 476-488.

Sondergaard, M., Kristensen, P. and Jeppesen, E., 1992. Phosphorus release from resuspended sediment in the shallow and windexposed Lake Arreso, Denamrk. *Hydrobiologia* **228**, 91-99.

Sozka, G.J., 1975. The invertebrates on submerged macrophytes in three Masurian lakes. *Ekologia Polska*, **23**(3), 371-391.

Sprung, M., 1989. Field and laboratory observations of *Dreissena polymorpha* larvae: abundance, growth, mortality and food demands. *Archiv fuer Hydrobiologie* **115**, 537-561.

Sprung, M. and Rose, U., 1988. Influence of food size and food quantity on the feeding of the mussel *Dreissena polymorpha*. *Oecologia* **77**, 526-532.

Stanczykowska, A., 1964. On the relationship between abundance aggregations and condition of *Dreissena polymorpha* Pall in 36 Mazurian Lakes. *Ekologia Polska* Series A **12**: 653-690.

Stanczykowska, A., 1968. The filtration capacity of populations of *Dreissena polymorpha* Pallas in different lakes, as a factor affecting circulation of matter in the lake. *Ekologia Polska* **14**, 265-270.

Stanczykowska, A., 1977. Ecology of *Dreissena polymorpha* (Pall.) (Bivalvia) in lakes. *Polskie Archiwum Hydrobiol*ogii **24**, 461-530.

Stanczykowska, A. and Planter, M., 1985. Factors affecting nutrient budget in lakes of the R. Jorka watershed (Masurian Lakeland, Poland) X. Role of the mussel *Dreissena polymorpha* (Pall.) in N and P cycles in a lake ecosystem. *Ekologia Polska* **33(2)**, 345-356.

Stanczykowska, A. and Lewandowski, K., 1993. Effect of filtering activity of *Dreissena polymorpha* (Pall.) on the nutrient budget of the littoral of Lake Mikolajskie. *Hydrobiologia* **251**, 73-79.

Sullivan, M., Lucy, F. and Minchin, D., 2002. The association between zebra mussels and aquatic plants in the Shannon River system, Ireland. *Aquatic Invaders* **13**, 6-9.

Ten Winkel, E.H. and Davids, C., 1982. Food selection by *Dreissena polymorpha*, Pallas (Mollusca: Bivalvia*). Freshwater Biology* **12**, 553-558.

Toner, P.F., 1979. *The trophic status of Irish lakes, Lough Key*. An Foras Forbatha, Dublin, WR/L8.

Tuchman, N.C., Burks, R.L., Call, C.A. and Smarrelli, J., 2004. Flow rate and vertical position influence ingestion rates of colonial zebra mussels (*Dreissena polymorpha*). *Freshwater Biology* **48**, 191-198.

Van der Velde, G., Paffen, B.G.P., Van den Brink, F.W.B., Bij de Vaate, A. and Jenner, H.A., 1994. Decline of zebra mussel populations in the Rhine; competition between two mass invaders (*Dreissena polymorpha* and *Corophium curvispinum*). *Naturwissenschaften* **81**, 32-34.

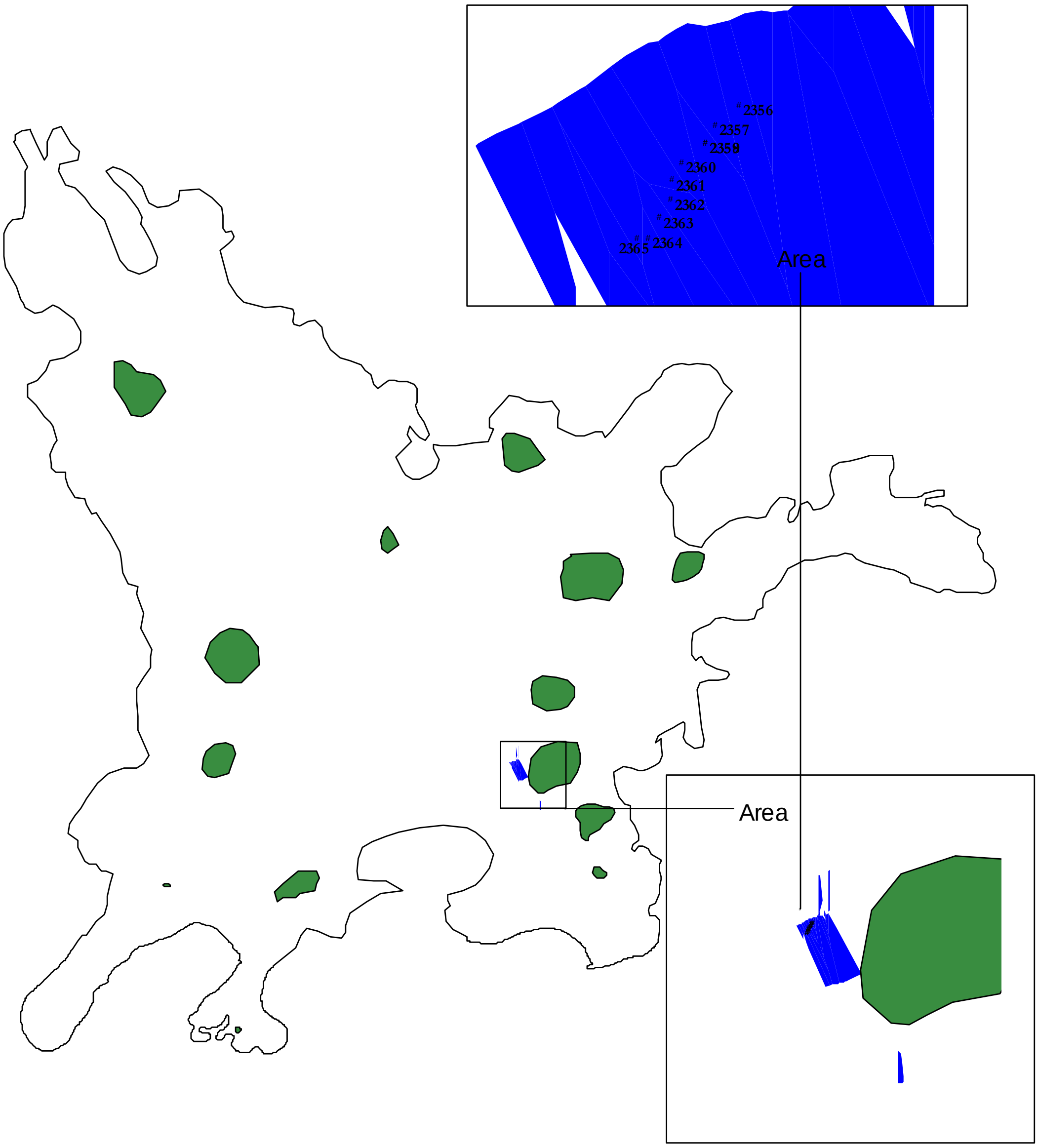
Vanderploeg, H.A., Johengen, T.H., Strickler, J.R., Liebig, J.R. and Nalepa, T.F., 1996. Zebra mussels may be promoting *Microcystis* blooms in Saginaw Bay and Lake Erie. *Bulletin of the North American Benthological Society* **13(1)**, 181-182.

Vollenweider, R.A., 1975. Input-output models, with special reference to the phosphorus loading model in limnology. *Schweizerische Zeitschrift fur Hydrologie* **37**, 53-84.

Walz, N., 1978 The energy balance of the freshwater mussel *Dreissena polymopha* Pallas in laboratory experiments and in Lake Constance. IV. Growth in Lake Constance. *Archiv fuer Hydrobiologie*. *Supplementband* **55**, 142-156.

Wilson, A.E., 2003. Effects of zebra mussels on phytoplankton and ciliates: a field mecocosm experiment. *Journal of Plankton Research* **25(8)**, 905-915.

Appendix 1 Specific Mapped Area for Gravel and Stones



Appendix 1: Lough Key Groundtruthing Survey

Grab Samples				Date: 17/08/01					
Site	**Grab No.**	**Ivor Ref.**	**WayPt Ref.**	**WayPt No.**	**Latitude and Longitude**	**Depth (m)**	**Zm Yes/No**	**New Settlement**	**Sediment Category**
Drummons Bay	1	Gravelly-sand	None	62	N53.98752 W008.24232	2.3	N	-	Soft Mud and *Anodonta*, Subsurface -gastropods, *Pisidium* & organic fibres
	2				N53.98686 W008.24066	1.4	Y (6g)	Not checked	Primarily mud with stone with zm. *P. lucens* and *Fontinalis*
	3				N53.98752 W008.24232	1.4	Y (20g)	Not checked	Primarily mud with stone, *L. trisulca*, Subsurface - gastropods
	4				N53.98752 W008.24232	1.4	Y (4g)	Not checked	Primarily mud with stone, trichoptera, *L. trisulca, P. lucens,* Subsurface -
Rockingham	1	Gravelly-sand	None	63	N53.98715 W008.23605	3.4	Y (18g)	Not checked	Rock and stone with zm
	2				N53.98715 W008.23605	3.4	Y (19g)	Not checked	Rock, stone and *Anodonta* with zm
	3				N53.98715 W008.23605	3.4	Y (6g)	Not checked	Stone with zm
Rockingham follie	1	Gravelly-sand	None	64	N53.98659 W008.23149	4.1	N	-	Mud only
	2				N53.98659 W008.23149	4.1	N	-	Mud only; Submerged gastropods and old *Anodonta*
	3				N53.98659 W008.23149	4.1	N	-	Mud only; Submerged gastropods and *Pisidium*
	4				N53.98659 W008.23149	4.1	N	-	Mud only; Submerged gastropods and plant detritus
W. Orchard Island	1	Gr-San	None	None	N53.99384 W008.23876	3.2	Y (11g)	Not checked	Gravel only and zm
	2				N53.99384 W008.23876	3.6	Y (25g)	Not checked	Stone and hit rock/stone
	3				N53.99384 W008.23876	3.2	Y (19g)	Not checked	Cobble and stone
N. Boyle River	1	Gravelly-sand	Ridboy	None	N53.90095 W008.26770	2.5	N	-	*Anondonta* stuck in the grab only
	2				N53.90095 W008.26770	2.7	Y	Not checked	Mud, stone with zm druse and old *Phragmites australis*
	3				N53.90095 W008.26770	2.6	Y	Not checked	*Anodonta* with zm druse, branch with zm druse, lot of old plant detritus and *Sparganium*

Appendix 1 (Contd): Lough Key Groundtruthing Survey

Grab Samples **Date: 17/08/01**

Site	**Grab No.**	**Ivor Ref.**	**WayPt Ref.**	**WayPt No.**	**Latitude and Longitude**	**Depth (m)**	**Zm Yes/No**	**New Settlement**	**Sediment Category**
NW Bullock	1	Area 1	None	66	N54.00528 W008.23640	5.6	N	-	Mud (shelly), gastropods
	2	Area 1	None	66	N54.00528 W008.23640	5.2	Y	Not checked	Mud (shelly), Anodonta with zm, druse (13 grams)
	3	Area 1	None	67	N54.00519 W008.23646	6.6	Y	Not checked	Mud (shelly), 1 Anodonta with zm, 2 Anodonta without am, druse (5 grams)
Long Isl Bay	1	Area 2	None	68	N54.01658 W008.27129	5.5	N	-	Mud (Silky), no zm
	2	Area 2	None	68	N54.01582 W008.27529	5.5	N	-	Mud (Silky), no zm
	3	Area 2	None	68	N54.01582 W008.27529	5.5	N	-	Mud (Silky), no zm
Long Isl Bay	1	Area 2	None	69	N54.01582 W008.27529	2.5	N	-	Mud (Shelly), no zm : > 10 grams of gastropod shell
	2	Area 2	None	69	N54.01582 W008.27529	2.5	N	-	Mud (Shelly and maerly), no zm : >10 grams of gastropod shell
	3	Area 2	None	69	N54.01582 W008.27529	2.5	N	-	Mud (Shelly), Anodonta - no zm
N. Hog Island	1	Unkonwn	None	70	N54.00511 W008.25889	13.4	N	-	Mud (Silky), no zm
	2	Unkonwn	None	70	N54.00511 W008.25889	13.2	N	-	Mud (Silky), no zm
	3	Unkonwn	None	70	N54.00511 W008.25889	13.2	N	-	Mud (Silky), no zm
N. Hog Island	1	Unkonwn	None	71	N54.00258 W008.25371	18.1	N	-	Mud (Silky), no zm
	2	Unkonwn	None	71	N54.00258 W008.25371	18.1	N	-	Mud (Silky), no zm
	3	Unkonwn	None	71	N54.00258 W008.25371	17.9	N	-	Mud (Silky), no zm
N. Hog Island	1	Unkonwn	None		N54.00717 W008.26059	18.1	N	-	Mud (Silky), no zm
	2	Unkonwn	None		N54.00717 W008.26059	18.1	N	-	Mud (Silky), no zm
	3	Unkonwn	None		N54.00717 W008.26059	17.9	N	-	Mud (Silky), no zm

Appendix 1 (Contd): Lough Key Groundtruthing Survey

Grab Samples **Date: 17/08/01**

Site	Grab No.	Ivor Ref.	WayPt Ref.	WayPt No.	Latitude and Longitude	Depth (m)	Zm Yes/No	New Settlement	Sediment Category
East Hog Isl	1	Unkn 8	None		N53.9971 W008.2535	10.5	N		Mud (Silky), no zm
	2		None		N53.9971 W008.2535	10.5	N		Mud (Silky), no zm
Hog Isl. deep buoy	1	Unknown	None	72& 73	N53.99830 W008.25055	24.0	N	-	Mud (Silky), no zm
N.W. Hermit Isl.	1	3522	None		N54.00616 W008.25027	15.5	N	-	Mud (Silky), no zm
	2	3522	None		N54.00717 W008.26059	15.6	N	-	Mud (Silky), no zm
	3	3522	None		N54.00717 W008.26059	15.3	N	-	Mud (Silky), no zm
S.E. Hermit Isl.	1	Unkn 9	None		N53.9988 W008.24305	12.3	N		Mud (Silky and fine shells), very fine plant detritus, no zm
	2		None		N53.9988 W008.24305	12.4	N		Mud (Silky and fine shells), decaying leaves; no zm
East of Boyle River	1	Area 3	None	74	N53.99161 W008.26354	4.2	N	-	Mud with some sand, *Anodonta* (small and large) under mud
	2	Area 3	None	74	N53.99161 W008.26354	4.2	N	-	Mud and plant detritus, old gastropods
	3	Area 3	None	74	N53.99161 W008.26354	4.4	N	-	Mud and plant detritus, old gastropods, peat ball
West Green Isl.	1		None	75	N53.99206 W008.23497	2.3	Y	Not checked	Rock with zm druse
	2		None	75	N53.99206 W008.23497	2.3	Y	Not checked	Rock with zm druse

Appendix 1 (Contd): Lough Key Groundtruthing Survey

Grab Samples **Date: 17/08/01**

Site	Grab No.	Ivor Ref.	WayPt Ref.	WayPt No.	Latitude and Longitude	Depth (m)	Zm Yes/No	New Settlement	Sediment Category
S. Hermit Isl. (Ridge)	1	None	None	90	N53.99652 W008.24724	13.7	N	-	Silky mud, one dead zm shell, a twig
	2			91	N53.99605 W008.24729	10.0	Y	Not checked	Rock with zm druse
	3			92	N53.99602 W008.24733	10.9	N	-	Mud, some small pebbles; Subsurface - old decaying *Anodonta*
	4			93	N53.99570 W008.24675	8.6	Y	Not checked	Stone with a few zm
	5			94	N53.99570 W008.24679	9.8	Y	Not checked	Stone with a few zm
	6			95	N53.99570 W008.24693	10.3	Y	Not checked	Stone/rock and mud
S. Hermit Isl.	1	GSSHER	None	None	N54.00139 W008.24899	4.5	Y	Not checked	Druses only
	2	Gravelly-			N54.00170 W008.24851	3.6	Y	Not checked	One zm and *Asellus*
	3	sand			N54.00170 W008.24851	4.2	Y	Not checked	Druses only - hit rock
	4				N54.00118 W008.24874	4.8	Y	Not checked	Druses only
	5				N54.00118 W008.24874	5.1	Y	Not checked	Gravel, pebbles and sand, dead zm and gastropods
	6				N54.00097 W008.24902	5.0	Y	Not checked	Gravel, pebbles and sand, druse and gastropods; clay under top layer
N. Hog Isl. (Ridge)	1	Gravelly -	None	99	N54.00332 W008.25872	4.7	Y	Y	Mud and *Anodonta* with zm and recent settlement
	2	sand		100	N54.00342 W008.25853	7.0	N	-	May have triggered early
	3			101	N54.00329 W008.25838	5.9	Y	Not checked	Mud with a lot of gastropods, some of which have zm druses attached (video)
	4			102	N54.00339 W008.25816	12.2	N	-	Mud with a lot of gastropods, some of which have zm druses attached (photox2)
	5			103	N54.00335 W008.25808	10.4	N	-	Mud with a lot of gastropods, some of which have zm druses attached (photox1)

Appendix 1 (Contd): Lough Key Groundtruthing Survey

Grab Samples, Lough Key **Date: 17/08/01**

Site	Grab No.	Ivor Ref.	WP. Ref.	WP No.	Latitude and Longitude	Depth (m)	Zm Yes/No	New Settlement	Sediment Category	Category Number
N. Boyle River	1	183	Tra	105	N 53.99091 W008.26791	2.2	N	-	Mud + plant debris + Sparganium	2
	2	183	Tra	106	N 53.99102 W008.26789	2.3	Y (1)	N	Mud + Peat + Roots	2
	3	183	Tra	107	N53.99101 W008.26790	2.3	Y	N	Mud + Ano (zm) + Sparganium + loose druse + zm on gastropod	2
East of Church	1	23	Tra 2	108	N53.99712 W008.25368	10.3	N	-	Mud (Silky)	1
	2	23	Tra 2	109	N53.99721 W008.25373	10.3	N	-	Mud + odd gastropod + odd dead zm	1
	3	23	Tra 2	110	N53.99708 W008.25368	10.4	N	-	Mud (Silky)	1
N.NE Hog Isl.	1	59	Tra 3	111	N54.00448 W008.25664	11.3	Y	N	Small zm druse	2
	2	59	Tra 3	112	N54.00451 W008.25663	11.5	N	-	Empty	2
	3	59	Tra 3	113	N54.00450 W008.25672	11.5	N	-	Empty	2
	4	59	Tra 3	114	N54.00450 W008.25672	11.4	Y	N	Mud, Gravel, gastropod + zm druse	2
	5	59	Tra 3	115	N54.00438 W008.25704	12.3	Y	N	Gastropods + zm druse	2
Near Hog Isl.	6	59	Tra 3	116	N54.00445 W008.25789	13.7	Y	N	Mud, Little gravel, plant debris	2
	7	59	Tra 3	117	N54.00454 W008.25818	13.4	N	-	Empty	2
	8	59	Tra 3	118	N54.00435 W008.25818	15.3	N	-	Empty	2
	9	59	Tra 3	119	N54.00438 W008.25824	14.5	N	-	Empty	2

Appendix 1 (Contd): Lough Key Groundtruthing Survey

Grab Samples, Lough Key **Date: 17/08/01**

Site	Grab No.	Ivor Ref.	WP. Ref.	WP No.	Latitude and Longitude	Depth (m)	Zm Yes/No	New Settlement	Sediment Category
100 m off Tra 3	10	59	Tra 3	120	N54.00442 W008.25830	14.3	N	-	Tripped early
120 m off Tra 3	11	59	Tra 3	121	N54.00444 W008.25848	14.7	Y	Y	zm druse only
130 m off Tra 3	12	59	Tra 3	122	N54.00452 W008.25862	14.7	N	-	Tripped early
130 m off Tra 3	13	59	Tra 3	123	N54.00459 W008.25865	14.2	N	-	Mud only
50 m off Tra 3	14	59	Tra 3	124	N54.00407 W008.25706	16.5	Y	N	Mud, stone submerged in mud
	15	59	Tra 3	125	N54.00402 W008.25721	16.3	Y	N	zm druse only
	16	59	Tra 3	126	N54.00402 W008.25743	17.3	N	-	Mud only
80 m off Tra 3	17	59	Tra 3	127	N54.00403 W008.25759	17.8	Y	?	Mud + small druse (3 zm)
90 m off Tra 3	18	59	Tra 3	128	N54.00403 W008.25787	18.9	N	-	Mud
East Hog Isl.	1	59		129	N 53.9964 W008.25786	0.5	Y	Y	Sand/Mud/gravel + most druses stuck to a piece of gravel (Rocky shore)
East Hog Isl.	2	59		130	N 53.9964 W008.25786	1.0	Y	Y	ZM on ash + sally trees (branches and roots)
									Anodonta bed here with 100% zm, density 7m2.
Centre Lake	1	1384	St-Roc	132	N53.99529 W008.24765	8.5	N	-	Empty
	2	1384	St-Roc	133	N53.99532 W008.24775	8.6	Y	Y	Druse only
	3	1384	St-Roc	134	N53.99536 W008.24786	10.6	Y	Y	Pebbles + zm -not drused
	4	1384	St-Roc	135	N53.99536 W008.24773	9.6	Y	Y	Rock, Pebbles, druse

Appendix 1 (Contd): Lough Key Groundtruthing Survey

Grab Samples **Date: 17/08/01**

Site	Grab No.	Ivor Ref.	WayPt Ref.	WayPt No.	Latitude and Longitude	Depth (m)	Zm Yes/No	New Settlement	Sediment Category	Category Number
Centre lake	1	1407	St-Ro2	136	N53.99678 W008.24730	11.2	Y	Y	Pebbles, druses	3
	2	1407	St-Ro2	137	N53.99690 W008.24800	12.5	Y	Y	Druse only	2
	3	1407	St-Ro2	138	N53.99683 W008.24752	12.7	Y	Y	Druse only	2
	4	1407	St-Ro2	139	N53.99686 W008.24754	12.4	Y	N	Single zm mussels	2
40 m from	5	1407	St-Ro2	140	N53.99647 W008.24706	13.2	Y	N	Mud + 1 zm	2
50 m from	6	1407	St-Ro2	141	N53.99634 W008.24705	12.9	Y	Y	Zm druse	2
Centre lake	1	1415	St-Ro3	142	N53.99706 W008.24787	13.9	Y	N	Zm druse	2
	2	1415	St-Ro3	143	N53.99715 W008.24781	15.4	N	-	Empty	2
	3	1415	St-Ro3	144	N53.99723 W008.24802	15.8	Y	Y	Zm druse	2
	4	1415	St-Ro3	145	N53.99722 W008.24746	17.6	N	-	Mud (Silky)	1
Centre lake	1	1421	St-Ro4	146	N53.99776 W008.24846	13.8	Y	Y	Druse + Mud + rope	2
20 m from	2	1421	St-Ro4	147	N53.99786 W008.24857	15.5	N	-	Mud (submerged gastropods and dead zm)	2
On site	3	1421	St-Ro4	148	N53.99760 W008.24842	15.6	Y	Y	*Fontinalis* + zm druse	2
30 m from	4	1421	St-Ro4	149	N53.99762 W008.24803	15.8	Y	Y	Mud (submerged gastropods and single live zm)	2
20 m from	1	1432	St-Ro5	150	N53.99820 W008.24880	13.7	N	-	Mud + *Cladophora*	1
10 m from	2	1432	St-Ro5	151	N53.99821 W008.24915	13.7	-	-	Didn't trigger	-
	3	1432	St-Ro5	152	N53.99811 W008.24890	15.8	Y	Y	Druse only	2
20 m from	4	1432	St-Ro5	153	N53.99809 W008.24881	13.3	Y	Y	Stone, pebble and druse..Dan took photo on pebble	3

Appendix 1 (Contd): Lough Key Groundtruthing Survey

Grab Samples **Date: 17/08/01**

Site	Grab No.	Ivor Ref.	WayPt Ref.	WayPt No.	Latitude and Longitude	Depth (m)	Zm Yes/No	New Settlement	Sediment Category	Category Number
SE Bullock	1	23450	Area 4	155	N54.00040 W008.22860	3.6	N	-	Mud mainly, silt and sand + *Fontinalis*	1
	2	23450	Area 4	156	N54.00038 W008.22840	1.7	Y	Y	Rock, Druse + *Cladophora*	4
	3	23450	Area 4	157	N54.00038 W008.22840	2.0	Y	Y	Rock and druse	4
	4	23450	Area 4	158	N54.00038 W008.22836	1.9	Y	Y	Rock and druse	4
SE Bullock	1	23226	Area 41	159	N54.00035 W008.22854	2.8	Y	Y	Rock, Druse + *Cladophora*	4
	2	23226	Area 41	160	N54.00042 W008.22843	3.2	Y	Y	Rock and druse	4
	3	23226	Area 41	161	N54.00046 W008.22836	3.0	Y	Y	Loose zm (rock)	4
W. Sally Isl	1	323	Area 3	162	N53.99752 W008.23849	3.6	Y	Y	Stone, gravel and druse	3
	2	323	Area 3	163	N53.99754 W008.23845	3.5	Y	Y	Stone, gravel and druse	3
	3	323	Area 3			3.5	Y	Y	Druse	3
	1	1388	Area 2	164	N53.99433 W008.23903	5.6	Y	Y	Gravel and druse	3
	2	1388	Area 2	165	N53.99435 W008.23898	5.6	Y	Y	Mud, gravel and druse	3
	3	1388	Area 2	166	N53.99440 W008.23882	5.4	Y	Y	Gravel and single zm's	3
	1	1393	Area 21	167	N53.99488 W008.23794	5.4	Y	Y	Mud, gravel, dead gastropds, pebble and druse	3
	2	1393	Area 21	168	N53.99489 W008.23781	4.9	Y	Y	Gravel and single zm's	3
	1	23828	Area 7	169	N53.98757 W008.26810	2.3	Y	Y	A lot of old plant debris (twigs, *Schoeno, Phrag*) Sparganium, druse	3
	2	23828	Area 7	170	N53.98766 W008.26804	2.4	Y	Y	A lot of old plant debris (twigs, *Schoeno, Phrag*) *Sparganium*, druse	3
	3	23828	Area 7	171	N53.98772 W008.26817	2.3	Y	Y	*Anodonta* x 2, mud and druse	3
	4	23828	Area 7	172	N5398771 W008.26821	2.2	N	-	Condensed plant debris	3

Appendix 1 (Contd): Lough Key Groundtruthing Survey

Grab Samples **Date: 17/08/01**

Site	Grab No.	Ivor Ref.	WayPt Ref.	WayPt No.	Latitude and Longitude	Depth (m)	Zm Yes/No	New Settlement	Sediment Category	Category Number
	1	1376	ST-Roc6	173	N53.99815 W008.24475	9.2	Y	Y	Druse only (rock)	3
	2	1376	ST-Roc6	174	N53.99825 W008.24477	10.1	Y	Y	Single zm's (rock)	3
	3	1376	ST-Roc6	175	N53.99840 W008.24481	10.2	Y	Y	Druse only (rock)	3
	1	327	327	176	N5400172 W008.24714	3.6	Y	Y	Single zm's (rock)	3
	2	327	327	177	N54.00177 W008.24720	3.4	Y	Y	Druse only (rock)	3
	3	327	327	178	N54.00183 W008.24729	2.9	Y	Y	Druse and singles (rock)	3
	1	334	334	179	N54.00511 W008.24873	3.1	Y	Y	Gravel and druse	3
	2	334	334	180	N54.00514 W008.24880	3.4	Y	Y	*Anodonta*, gravel and druse	3
	3	334	334	181	N54.00520 W008.24864	3.9	Y	Y	Druse only (rock)	4
	4	334	334	182	N54.00529 W008.24877	5.6	Y	Y	Druse only (rock)	4
	1		Area 6	183	N54.01200 W008.26908	2.4	Y	Y	*Cladophora* mats and zm druses	3
	2		Area 6	184	N54.01200 W008.26914	2.4	Y	Y	zm attahced to caddis, stones and gravel,	3
	3		Area 6	185	N54.01203 W008.26919	2.6	Y	Y	*Cladophora*, gravel, druse	3
Between St-Ro2	1	None	None	186	N53.99694 W008.24787	13.4	N	-	Mud and dead zm	1
and St-Ro3	2			-	Missed input	12.8	Y	Not checked	Stone and live single zm's	3
				187	N53.99707 W008.24789	13.4	Y	Y	Stone and live single zm's - grab stuck on rock	3
Between St-Ro3	1	None	None	188	N53.99749 w008.24813	17.1	N	-	Mud only	1
and St-Ro4	2			189	N53.99743 W008.24823	17.5	Y	Not checked	Rock and druse	3

Appendix 1 (Contd): Lough Key Groundtruthing Survey

Grab Samples				**Date: 17/08/01**						
Site	**Grab No.**	**Ivor Ref.**	**WayPt Ref.**	**WayPt No.**	**Latitude and Longitude**	**Depth (m)**	**Zm Yes/No**	**New Settlement**	**Sediment Category**	**Category Number**
Between St-Ro4	1	None	None	190	N53.99799 W008.24858	14.6	Y	Not checked	Mud mainly, plant debris, gastropods, few single live zm and dead zm's	2
and St-Ro5	2			191	N53.99800 W008.24835	15.7	N	-	Mud only	1
	3			192	N53.99807 W008.24852	13.4	Y	Not checked	Rock and druse	3
West Bullock Isl.	1	None	None	193	N54.00178 W008.24001	3.7	Y	Not checked	Stone and single zm's	3
	2			194	N54.00187 W008.24009	3.7	Y	Not checked	Stones and zm's on them	3
	3			195	N54.00179 W008.24016	3.0	Y	Not checked	Rock and single zm's	4
	4			196	N54.00169 W008.24025	3.4	Y	Not checked	Mud, rock and druse	3
	5			197	N54.00153 W008.23960	2.6	Y	Not checked	Stones and zm's on them	3
	6			198	N54.00165 W008.23964	3.0	Y	Not checked	Rock and druse	4
	7			199	N54.00174 W008.23968	3.4	N	-	Nothing	-
	8			200	N54.00178 W008.23976	3.5	N	-	Rock – empty	4
	9			201	N54.00203 W008.24011	5.0	N	-	Mud	1
	10			202	N54.00092 W008.23993	3.6	Y	Not checked	Rock and druse	4
	11			203	N54.00090 W008.24013	3.9	N	-	Mud (very shelly)	2
	12			204	N54.00093 W008.24050	5.3	N	-	Mud (very shelly)	2
	13			205	N54.00217 W008.24681	3.7	Y	Not checked	*Cladophora* and zm	2
	14			206	N54.00218 W008.24694	4.2	Y	Not checked	Single zm's	2
	15			207	N54.00217 W008.24706	3.9	Y	Not checked	*Cladophora* and zm	2

Appendix 1 (Contd): Lough Key Groundtruthing Survey

Grab Samples **Date: 17/08/01**

Site	Grab No.	Ivor Ref.	WayPt Ref.	WayPt No.	Latitude and Longitude	Depth (m)	Zm Yes/No	New Settlement	Sediment Category	Category Number
West Bullock Isl.	16			208	N54.00190 W008.24789	3.1	Y	Not checked	Gravel and zm (33mm shellof zm here)	3
	17			209	N54.00189 W008.24792	3.6	Y	Not checked	Mud, gravel and zm	2
	18			210	N54.00195 W008.24810	4.3	Y	Not checked	Mud, gravel, gastropods and zm	3
	19			211	N54.00206 W008.24833	6.0	N	-	Mud (maerly)	1
	20			212	N54.00222 W008.24864	9.0	N	-	Mud (Silky)	1
	21			213	N54.00183 W008.24797	3.3	Y	Not checked	Rock and druse	4
	22			214	N54.00173 W008.24803	2.7	N	-	Rock	4
	23			215	N54.00156 W008.24802	3.3	Y	Not checked	Rock and druse	4
	24			216	N54.00151 W008.24823	3.5	Y	Not checked	Rock and druse	4
	25			217	N54.00144 w008.24837	3.7	Y	Not checked	Rock and druse	4
	26			218	N54.00130 W008.24854	3.9	N	-	Rock - nothing	4
	27			219	N54.00123 W008.24860	4.1	N	-	Rock - nothing	4
	28			220	N54.00119 W008.24865	4.2	N	-	Rock - nothing	4
	29			221	N54.00112 W008.24872	4.9	N	-	Rock - nothing	4
	30			222	N54.00098 W008.24884	5.2	N	-	Pebbles and maerl	2
	31	None	None	223	N54.00069 W008.24910	5.1	N	-	Maerl and gastropods	2
	32			224	N54.00062 W008.24912	5.1	N	-	maerl, pebbles, and zm shell	3
	33			225	N54.00050 W008.24921	5.1	N	-	Rock , empty	4

Appendix 1 (Contd): Lough Key Groundtruthing Survey

Site	Grab No.	Ivor Ref.	WayPt Ref.	WayPt No.	Latitude and Longitude	Depth (m)	Zm Yes/No	New Settlement	Sediment Category	Categ Numl
Grab Samples				Date: 17/08/01						
	34			226	N54.00039 W008.24927	5.3	N	-	Rock , empty	4
	35			227	N54.00025 W008.24936	5.4	N	-	Rock , empty	4
	36			228	N54.00024 W008.24936	5.4	N	-	Rock , empty	4
	37			229	N54.00020 W008.24941	5.4	N	-	Mud and gastropods	2
St-Roc6	38	None	None	230	N54.00166 W008.24836	3.0	Y	Not checked	Druse	3
	39			231	N53. 99826 W008.24444	10.2	Y	Not checked	Some single zm's	3
	40			232	N53.99828 W008.24467	9.3	N	-	Rock , empty	4
	41			233	N53.99832 W008.24486	11.1	N	-	Mud and gastropods	1
	42			234	N53.99823 W008.24454	9.1	Y	Not checked	Some single zm's	3
	43			235	N53.99833 W008.24479	10.2	N	-	Rock , empty	4
	44			236	N53.99811 W008.24450	9.2	Y	Not checked	Druse	3
	45			237	N53.99820 W008.24453	9.1	Y	Not checked	Cobble, stone and zm's on them	3
Area 2	46			238	N53.99412 W008.23917	5.6	Y	Not checked	Stone with zm's	3
	47			239	N53.99410 W008.23924	6.1	Y	Not checked	Druse	3
	48			240	N53.99409 W008.23924	5.8	-	-	Didn't trigger	3
	49			241	N53.99409 W008.23929	6.1	-	-	Druse	3
				242	N53.99620 W008.24668				No sample taken here	
John 2	50			243	N53.99625 W008.24675	12.3		-		
	51			244	N53.99618 W008.24716	11.7		-		

Appendix 2: Halia Oceanographic Video : Substrate Analysis

Tape No. 1

				Susbtrate (%)								Plants						
Date	WP	Boat/Shore	Video time	Rock	Stone	Mud	Anodonta	Plant debris	Pebbles	**% Cover**	Anodonta **(m^2)**	*S. lacustris*	*P. australis*	*N. lutea*	*E. canadensis*	*S. emersum*	*L. trisulca*	*Potamogeton sp.*
06/09/01	10a	Shore	-1.23/+2.07.11		5	95	5	<5		100	2	+				+		
06/09/01	13	Boat	-1.17/+2.13.28		<5	95	<5			100	3			+		+		
06/09/01	13a	Shore Island	-1.10/+2.20.36	5	50	40	5			100	?	+				+		+
06/09/01	16	Boat (W. of isl)	-1.01/+2.29.25			100	<1			100	<1			+		+	+	
06/09/01	16a	Shore Island (W. of isl)	-0.53/+2.38.40		<1	100	<1	<5		100	<1	+		+	+	+		
06/09/01	19a	150m W. of WP 19 (Shore)	-0.45/2.46.22		<1	100		<5		100	<1			+		+	+	
06/09/01	19	150m E. of WP 19 (Boat)	-0.36/+2.55.47															
06/09/01	21	Shore	-0.31/+3.00.04		<1	100	<1			100	1				+	+		
06/09/01	25	Shore	-0.25/+3.06.31		<5	100	<1			100	1					+		
06/09/01	27	Shore	-0.19/+3.12.47		5	95	<5			100	3			+		+		

Tape No. 2

13/06/01	57	Shore	0.00.31-0.05.55	50	50					70	0-1			+				
13/06/01	58	Shore	0.06.00	10		90				50	2	+		+	+	+	+	
13/06/01	59	Shore	0.11.00	70	30					55	0			+				+
13/06/01	60	Shore	0.16.07	70	30					50	0							
13/06/01	61	Shore	0.19.58			100				100	1							
13/06/01	61	Shore	0.24.37	50	50					50	0							
13/06/01	62	Boat	0.26.03			100				100	1				+		+	
13/06/01	62A	Shore (270m e of 62)	0.31.26	5	30	65				50	2	+		+	+			

Appendix 2 (Contd.): Halia Oceanographic Video : Substrate Analysis

Tape No. 2

				Susbtrate (%)								Plants							
Date	WP	Boat/Shore	Video time	Rock	Stone	Mud	Anodonta	Plant debris	Pebbles	**% Cover**	Anodonta **(m^2)**	*S. lacustris*	*P. australis*	*N. lutea*	*E. canadensis*	*S. emersum*	*L. trisulca*	*Potamogeton sp.*	
13/06/01	63	Boat	0.35.52			100				100	1						+		+
13/06/01	64	Boat	0.41.30	60	30	10				50	0				+				+
13/06/01	65	Boat	0.45.02	70	30					40	0								
13/06/01	65A	Shore	0.50.31	70	30					40	0								+
13/06/01	66	Boat	0.52.10			100				100	1								+
13/06/01	66A	Shore (60m west of 66)	0.58.01	70	30					40	0			+	+	+		+	
13/06/01	67	Shore	1.03.01	50	40				10	85	0								+
13/06/01	68	Shore	1.11.17	50	40				10	60	0								+
13/06/01	69	Shore	1.18.04		10	90				100	1			+	+	+		+	+
13/06/01	70	Shore	1.24.24	70	25				5	60	0								+
13/06/01	71	East of rocky outcrop	1.29.26			100				0	0								
13/06/01	72	Shore	1.30.00	45	30	25	<5			50	1								+
13/06/01	73	Reeds	1.36.30		5	95				100	3	+				+			+
14/06/01	74	Shore	1.42.07		20	75	5			100	4	+			+				+
14/06/01	75	Shore	1.47.50	5	5	90				90	3			+	+				
14/06/01	76	Shore	1.53.00	80	20					90	0								+
14/06/01		Shore			10	90				100	3				+	+			+
14/06/01	77	Shore	1.58.37			100				100	<1								
14/06/01	77A	Shore	2.02.00	75	20	3				80	0								

Appendix 2 (Contd.): Halia Oceanographic Video : Substrate Analysis

Tape No. 2

				Susbtrate (%)								Plants							
Date	WP	Boat/Shore	Video time	Rock	Stone	Mud	Anodonta	Plant debris	Pebbles	**% Cover**	Anodonta **(m^2)**	*S. lacustris*	*P. australis*	*N. lutea*	*E. canadensis*	*S. emersum*	*L. trisulca*	*Potamogeton sp.*	*Cladophora*
14/06/01	1	Shore	2.05.07		10	85	5			100	3	+		+	+	+			+
14/06/01	2	Shore	2.11.00		15	80	5			90	2	+		+	+	+	+		+
14/06/01	3	Shore	2.16.50		10	85	5			100	1	+				+			
14/06/01	4	Shore	2.22.00		10	90				90	1	+				+			
14/06/01	5	at WP	2.26.40		5	90	5			100	3	+		+	+	+		+	+
14/06/01	6	Shore	2.37.25		20	75	5			100	3	+		+		+			+
14/06/01	7	Shore	2.43.45	20	40	35	5			100	3	+			+	+			
14/06/01	8	WP	2.50.04																
14/06/01	9	WP	2.50.30		5	90	5			100	2	+				+			+
14/06/01	10	WP	2.55.50		<5	95	5			100	3					+			
14/06/01	10A	Shore	3.00.05		5	95				100	1	+				+			+
14/06/01	11	WP	3.03.35		5	95				100	1								+
14/06/01	11A	Shore	3.09.40		5	95				100	1			+					+
14/06/01	12	Shore	3.15.00		10	85	5			100	5	+		+	+			+	+
14/06/01	13	Shore	3.20.45	70	20	5	5			80	3					+			
14/06/01	14	Shore	3.27.54	80	20					80	0								
14/06/01	15	Shore	3.31.00	65	20	15				80	2								
14/06/01	16	Shore	3.36.00	60	10	30				100	3			+		+			+
14/06/01	17	Shore	3.42.50		5	90	5			100	5			+		+			

Appendix 2 (Contd.): Halia Oceanographic Video : Substrate Analysis

Tape No. 3

				Susbtrate (%)								Plants							
Date	WP	Boat/Shore	Video time	Rock	Stone	Mud	Anodonta	Plant debris	Pebbles	**% Cover**	Anodonta **(m^2)**	*S. lacustris*	*P. australis*	*N. lutea*	*E. canadensis*	*S. emersum*	*L. trisulca*	*Potamogeton sp.*	*Cladophora*
17/06/01	18A	50 m west of 18	0.00.00		<5	95	<5			100	2	+		+	+	+			
17/06/01	19	Middle of Lake	0.10.05																
17/06/01	20	Shore	0.10.13	25	25	50				90	3	+			+	+		+	+
17/06/01	21	Island Shore	0.19.08								5					+		+	+
17/06/01	22	Mainland Shore	0.26.30	50	20	25	5			10	6					+			+
17/06/01	23	Island Shore	0.31.47	55	20	25				80	1	+			+	+			+
17/06/01	24	Mainland Shore	0.38.22	10	10	65	5		10	75	3			+		+		+	+
17/06/01	25A	N. side of Island	0.45.20	25	20	50			5	90	2	+						+	+
17/06/01	26	Mainland Shore	0.49.01			80	15	<1	5	100	12			+	+	+			
17/06/01	27	West of Island	0.57.51	35	20	40	5	<1		100	5	+			+			+	
17/06/01	28	Mainland Shore	1.02.01			100				100	1			+	+	+			
17/06/01	29	Boat and shore	1.04.45 (Tape 1)		5	90		5		20	0	+		+	+	+	+	+	
17/06/01	30	Shore	1.00.57 (Tape 1)			100				100	1					+			
17/06/01	31	South of Island	1.11.23	0	<5	90	<5			100	2				+	+			
17/06/01	32A	70 m west of 32	1.15.06			100				100	1	+		+		+			+
17/06/01	34	Shore	1.20.28	60	10	25	5	<1	<5	100	5			+		+			+
17/06/01	35A	70 m east of Shore	1.26.06	70	10	20				70	3			+	+	+			+

Appendix 2 (Contd.): Halia Oceanographic Video : Substrate Analysis

Tape No. 3

				Susbtrate (%)								Plants							
Date	WP	Boat/Shore	Video time	Rock	Stone	Mud	Anodonta	Plant debris	Pebbles	**% Cover**	Anodonta **(m²)**	*S. lacustris*	*P. australis*	*N. lutea*	*E. canadensis*	*S. emersum*	*L. trisulca*	*Potamogeton sp.*	
17/06/01	36	Shore	1.32.11	60	10	30			<5	80	3			+	+	+			+
17/06/01	37	Marker Buoy	1.39.19			100				100	1								
17/06/01	38	Island	1.43.55			100				0	0						+		
17/06/01	39	Shore	1.48.37		10	85			5		1	+		+		+			+
17/06/01	40	Shore	1.55.46	60	30	10				85	0	+		+					+
17/06/01	41	50 m from 40	2.00.40																
17/06/01	42	Boat	2.00.46			100				100								+	
17/06/01	43	Video not working																	
17/06/01	44	No WP given	2.22.24		15	80	5			100	4			+		+	+		+
6/7/2001	45	Shore	2.27.44		5	95				100	1	+		+	+	+	+		+
6/7/2001	46	Shore	2.34.52			100				100	1			+					+
7/7/2001	47	Shore	2.40.15			100					0			+				+	+
7/7/2001	48	Shore	2.42.09		10	85	5			100	3	+			+	+	+		+
7/7/2001	49	Shore	2.49.24	5		100				5						+			+
7/7/2001	50	Shore	2.53.17	30	20	50				90	1	+			+	+			+
7/7/2001	51	Shore	2.57.34	20	30	50				100	1								+
7/7/2001	52	60 m north 52-Island	3.01.06	35	25	35			5	70	1		+		+	+	+	+	+
7/7/2001	53	North of Island	3.10.10	35	25	30			10	85	1								+
7/7/2001	54	North of Island	3.18.47	70	30	0				90	<1								+
7/7/2001	55	70 m west of E. Island	3.22.19	70	10	10			10	90	<1				+				+

Appendix 3: Chlorophyll *a* and Transparency, Lough Key 2000-2003

	Chlorophyll *a* ug					Transparency/m				
Date	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
28/01/2001	0.49	0.00	0.78	ND	ND	1.3	1.2	1.6	ND	ND
19/02/2002	2.62	ND	3.79	3.01	ND	1.5	1.3	ND	1.3	ND
22/03/2002	4.08	3.21	3.50	4.76	ND	1.7	1.5	1.7	1.3	ND
17/03/2003	3.21	6.03	3.50	3.21	ND	1.4	1.5	1.6	1.5	-
01/04/2001	3.12	4.84	3.63	3.53	ND	1.5	1.4	1.6	1.0	-
07/04/2002	1.17	1.95	1.36	1.26	ND	1.5	1.7	1.6	1.3	ND
13/04/2001	3.83	12.10	3.22	2.02	ND	2.0	1.3	2.0	0.8	-
11/04/2003	3.89	7.49	4.87	6.32	ND	2.2	1.8	2.1	1.7	ND
25/04/2002	2.33	2.72	3.31	4.18	ND	1.7	1.6	2.0	1.6	ND
01/05/2001	0.97	0.00	0.39	0.29	ND	2.0	1.8	1.7	0.8	-
09/05/2002	3.50	6.42	4.96	5.64	ND	2.5	2.3	2.4	1.8	ND
15/0520/01	5.05	3.89	4.28	3.02	ND	1.8	2.0	2.0	1.5	ND
16/05/2003	3.99	3.79	5.35	3.26	ND	2.2	2.2	2.3	1.7	ND
29/05/2001	3.50	3.30	0.58	4.28	0.58	2.0	2.0	2.0	1.7	2.1
30/05/2002	2.72	4.77	3.11	2.33	ND	1.8	1.3	2.2	2.0	ND
31/05/2003	3.70	8.17	5.06	5.06	ND	2.1	1.8	2.2	1.9	ND
10/06/2001	0.00	0.00	1.36	4.86	1.75	1.8	1.6	2.0	1.7	1.5
12/06/2002	1.65	2.14	1.95	2.53	ND	1.8	1.6	1.7	1.5	ND
18/06/2002	ND	1.56	1.75	5.55	ND	ND	1.6	1.7	1.6	ND
15/06/2003	7.88	3.89	11.18	10.99	6.22	2.2	2.1	2.2	1.8	2.1
23/06/2001	4.08	4.48	1.95	3.89	4.67	2.0	1.9	1.9	2.1	1.2
28/06/2002	5.10	3.89	4.87	3.50	ND	2.2	2.0	2.3	2.0	ND
30/06/2000	14.79	9.93	7.88	14.89	13.63	2.0	1.9	1.9	0.4	1.9
30/06/2001	5.05	5.45	5.84	3.50	3.50	1.8	1.7	2.0	0.9	2
30/06/2003	5.75	7.49	7.88	7.88	10.22	2.8	2.5	3.0	1.8	2.7
07/07/2000	4.48	6.03	4.28	14.80	3.11	2.4	2.5	2.3	0.5	2
06/07/2001	4.48	3.31	3.89	4.96	2.53	2.5	1.8	3.1	2.4	0.8
06/07/2002	3.31	3.60	7.30	5.94	5.35	1.9	1.8	1.9	1.8	1.8
07/07/2003	6.03	9.73	9.05	4.77	4.09	2.1	2.1	2.8	1.8	2.4
14/07/2000	5.26	2.43	3.60	3.02	17.71	2.4	2.0	2.5	0.9	1.9
15/07/2001	3.69	6.42	5.05	3.31	3.70	2.3	1.7	2.3	2.7	1.5
13/07/2002	9.24	3.89	5.45	5.74	3.11	ND	ND	ND	ND	1.5
14/07/2003	5.35	3.41	3.89	6.52	8.17	2.6	2.3	2.8	1.8	2.6

Note: ND means no data, either due to seasonal sampling or adverse weather

Appendix 3 (Contd): Chlorophyll *a* and Transparency, Lough Key 2000-2003

	Chlorophyll *a* ug					Transparency/m				
Date	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
21/07/2000	7.69	10.90	10.22	5.14	ND	1.5	1.4	1.9	0.6	ND
21/07/2001	5.45	1.95	3.31	3.70	2.92	2.3	1.8	2.6	1.3	2.5
21/07/2002	7.20	7.49	9.63	5.83	7.49	1.8	1.7	1.9	1.1.	1.7
22/07/2003	12.84	6.42	22.38	11.38	6.52	2.3	2.4	2.1	1.6	2.6
28/07/2000	14.92	2.72	12.80	2.62	7.36	1.8	2.0	2.0	0.7	2.2
28/07/2001	12.84	24.70	12.40	26.85	11.29	2.7	2.9	2.7	1.7	2.8
28/07/2002	4.96	5.35	3.41	4.09	5.74	2.0	1.6	1.7	1.3	1.8
29/07/2003	6.91	5.64	11.19	6.32	10.9	2.3	2.4	2.3	1.8	2.3
04/08/2000	3.22	1.91	2.62	5.14	3.83	2.2	2.0	2.2	0.6	2.2
03/08/2001	8.47	13.03	18.97	9.93	9.83	2.9	2.8	2.9	1.0	3.1
04/08/2002	5.94	6.03	5.45	5.45	3.11	1.8	1.8	1.5	1.4	1.8
05/08/2003	4.87	10.41	5.35	5.84	12.16	2.4	1.8	2.2	1.5	2.2
11/08/2000	17.23	3.12	2.32	5.44	3.63	2.4	2.0	2.4	0.6	2.4
11/08/2001	2.72	3.50	7.20	3.70	5.55	2.7	2.8	2.7	0.8	2.1
13/08/2002	4.67	3.11	5.55	4.87	6.13	2.1	1.9	2.0	1.5	2.2
13/08/2003	9.83	9.05	10.41	7.01	10.41	2.3	2.4	2.4	1.7	2.3
18/08/2000	7.46	8.97	15.16	8.77	13.1	2.5	2.3	2.5	0.4	2.5
18/08/2001	5.06	6.62	3.11	5.16	5.94	2.7	2.8	2.6	0.8	2.8
18/08/2002	4.96	ND	2.14	5.35	5.35	2.1	2.1	2.4	1.5	2.2
19/08/2003	3.21	3.70	4.09	3.60	3.99	2.7	2.5	2.6	1.7	2.6
26/08/2000	9.78	11.49	5.54	8.36	7.76	1.9	1.9	2.3	0.9	2.2
24/08/2001	2.92	2.14	5.74	2.72	3.31	2.7	2.7	2.8	1.8	2.8
23/08/2002	6.03	9.73	6.81	4.18	2.72	2.3	2.3	2.3	1.7	2.3
26/08/2003	3.21	5.25	3.99	4.77	7.59	2.6	2.6	2.5	1.7	2.7
31/08/2002	3.89	2.63	3.60	3.89	4.48	2.4	2.3	2.4	1.5	2.2
02/09/2000	2.62	6.55	4.94	ND	ND	2.5	2.5	2.4	0.6	2.3
02/09/2001	3.02	7.88	3.50	3.79	3.31	3.4	2.9	3.0	1.7	3
02/09/2003	9.34	13.52	12.16	7.78	9.83	3.0	2.5	2.4	1.7	2.7

Note: ND means no data, either due to seasonal sampling or adverse weather

Appendix 3 (Contd): Chlorophyll *a* and Transparency, Lough Key 2000-2003

	Chlorophyll *a* ug					Transparency/m				
Date	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
07/09/2000	-	-	-	-	-	3.1	2.9	ND	ND	ND
08/09/2001	3.79	ND	2.62	3.21	2.72	2.8	2.4	3.1	0.8	2.8
12/09/2002	2.13	3.11	2.04	2.72	2.91	2.7	2.4	2.4	1.7	2.6
09/09/2003	7.59	8.76	13.04	8.37	8.56	2.8	2.4	2.7	1.6	2.9
16/09/2000	ND	ND	ND	ND	1.75	3.1	2.2	2.8	0.6	2.5
20/09/2001	3.02	4.57	6.23	8.27	4.38	3.0	3.0	3.0	1.8	2.6
19/09/2002	3.70	5.84	7.49	3.50	6.13	2.9	1.8	2.0	1.8	2.7
21/09/2003	9.34	9.54	8.56	6.91	5.45	3.0	2.8	3.0	1.7	2.5
01/10/2000	2.14	3.02	4.28	1.56	1.56	2.6	2.4	2.7	0.6	2.4
30/09/2001	3.11	4.38	4.28	8.27	7.00	2.7	2.3	3.0	1.5	2.5
01/10/2002	3.89	3.41	2.82	4.38	2.24	2.7	2.5	2.6	1.0	2.6
11/10/2001	ND	ND	7.20	8.15	ND	ND	ND	2.9	1.0	ND
11/10/2003	5.35	6.03	5.06	4.96	ND	3.2	2.9	3.1	1.8	2.8
22/10/2000	1.75	2.14	1.36	1.85	1.85	2.0	1.7	2.0	0.7	1.7
21/10/2001	3.79	3.79	5.25	3.69	3.50	2.6	2.3	2.6	1.9	2.6
28/10/2002	4.28	6.91	5.35	4.87	ND	2.0	1.1	1.8	ND	ND
30/11/2002	4.50	6.03	3.99	6.62	ND	1.2	1.2	1.1	1.0	ND
10/12/2000	0.68	0.20	0.01	0.39	ND	1.0	0.9	1.0	0.5	ND
09/12/2001	1.95	2.72	2.43	0.97	ND	1.4	1.4	1.4	1.2	ND

Note: ND means no data, either due to seasonal sampling or adverse weather

Appendix 4: EPA water quality data for Lough Key, 2001

Date Sampled	Station	Temp °C	DO % Sat	Secchi m	pH	Cond µS/cm	Colour Hazen	NH3 mg N	PO4 µg P	TON mg N	TP µg P	Chlorophyll mg/m³	Silica mg Si
05/04/2001	A	7.5	11.1	1.8	8.2	337	-	0.031	47	0.594	1304	2	1.664
05/04/2001	B	7.3	11.2	1.9	8.2	334	-	0.022	32	0.615	29	1.6	2.222
05/04/2001	B/6	7.4	10.9	-	8.2	335	-	0.041	31	0.618	47	-	1.869
05/04/2001	C	7.3	11.1	1.9	8.2	333	-	0.033	38	0.619	32	1.6	1.979
05/04/2001	C/18	7.3	10.9	-	8.2	333	-	-0.011	21	0.576	29	-	1.895
05/04/2001	D	7.3	11.4	2.3	8.2	334	-	-0.008	20	0.592	141	0.8	2.24
05/04/2001	D/6	7.4	10.7	-	8.2	334	-	0.076	7	0.598	2245.9		2.2
05/04/2001	E	7.5	10.9	2	8.2	339	-	0.007	18	0.598	21	1.6	2.09
05/04/2001	E/6	7.7	10.8	-	8.1	342	-	0.052	23	0.616	31	-	1.978
04/07/2001	A/S	18.3	93	3	-	-	-	0.003	9.578	0.222	117	5.6	0.848
04/07/2001	A/6m	18.2	96	-	-	-	-	0.019	7.248	0.223	106	-	0.866
04/07/2001	B/S	18.7	92	3.2	-	-	-	0.005	8.098	0.264	90	6	0.937
04/07/2001	B/6m	17.8	86	-	-	-	-	0.014	13.333	0.276	43	-	0.989
04/07/2001	C/S	18.2	95	2.8	-	-	-	0.011	8.905	0.258	53	4.4	0.834
04/07/2001	C/12m	17.9	96	-	-	-	-	0.014	10.347	0.268	42	-	0.922
04/07/2001	C/18m	18.4	70	-	-	-	-	0.003	24.763	0.345	61	-	1.391
04/07/2001	D/S	18.4	93	3.3	-	-	-	0.006	8.336	0.247	34	6	0.841
04/07/2001	D/6m	17.6	86	-	-	-	-	0.032	15.988	0.283	37	-	0.973
04/07/2001	E/S	18.4	98	3.3	-	-	-	0.004	9.245	0.252	32	5.2	0.901
04/07/2001	E/6m	18.4	94	-	-	-	-	0.011	12.575	0.257	82	-	0.956
06/09/2001	A/6m	17.2	90	3.5	8.26	367	70	0.01	17	0.15	37	3.6	1.641
06/09/2001	B/5m	17.2	92	3.3	8.2	365	80	0.01	15	0.15	31	4	1.541
06/09/2001	C/S	17.2	90	3.9	8.22	368	70	0.01	12	0.15	29	4	1.556
06/09/2001	C/18m	17.2	92	-	8.21	363	70	0.02	18	0.15	133	4.4	1.527
06/09/2001	D/S	16.9	90	3.6	8.2	365	80	0.01	18	0.15	49	6.4	1.591
06/09/2001	D/5m	17	99	-	8.22	368	80	0.02	15	0.15	39	2.8	1.556
06/09/2001	E/S	17.4	91	3.5	8.21	370	60	0.01	17	0.15	53	5.6	1.567
03/10/2001	A/S	14.2	94	2.8	8.24	361	70	0.02	18	0.21	-	2	-
03/10/2001	A/6m	14	93	-	8.23	356	90	0.04	19	0.22	-	-	-
03/10/2001	B/S	14.5	95	2.9	8.3	367	60	0.01	12	0.19	-	-	-
03/10/2001	B/6m	14.5	95	-	8.33	368	60	0.02	18	0.19	-	-	-
03/10/2001	C/S	14.3	95	2.7	8.29	366	60	0.02	19	0.2	-	2	-
03/10/2001	C/18m	14.3	90	-	8.26	365	70	0.02	19	0.2	-	-	-
03/10/2001	D/S	14.2	93	3.3	8.28	366	60	0.02	18	0.2	-	1.6	-
03/10/2001	D/6	14.3	91	-	8.29	365	70	0.03	15	0.2	-	-	-
03/10/2001	E/S	14.3	93	3.1	8.19	374	60	0.02	13	0.23	-	4.4	-

Appendix 4 (Contd.): EPA water quality data for Lough Key, 2001

Date Sampled	Station	Temp °C	DO % Sat	Secchi m	pH	Cond µS/cm	Colour Hazen	NH3 mg N	PO4 µg P	TON mg N	TP µg P	Chlorophyll mg/m³	Silica mg Si
20/03/2002	A	6.5	90	1.9	-	-	90	<0.01	11	0.55	25	2.4	0.830
20/03/2002	B	6.6	93	2	-	-	90	0.02	11	0.58	22	2.4	0.960
20/03/2002	C	6.5	91	2	-	-	90	<0.01	<10	0.57	20	2.8	1.280
20/03/2002	C/18	6.6	93	-	-	-	80	0.02	<10	0.59	21	-	1.100
20/03/2002	D	6.6	91	2.2	-	-	90	<0.01	<10	0.58	28	2.4	1.320
20/03/2002	E	6.6	91	1.9	-	-	80	0.01	15	0.57	33	2.8	1.190
04/07/2002	A	15.7	92	2.1	8.18	317	100	<0.01	17	0.31	41	1.2	1.130
04/07/2002	B	15.5	92	2.3	8.19	317	100	0.02	16	0.32	26	1.2	1.150
04/07/2002	B/6	15.4	91	-	8.18	318	100	0.01	15	0.32	31	-	1.290
04/07/2002	C	15.5	90	2.2	8.18	317	100	<0.01	17	0.31	33	1.6	1.390
04/07/2002	C/20	15.5	91	-	8.17	317	100	<0.01	17	0.31	182	-	1.190
04/07/2002	D	15.5	93	2.6	8.18	315	100	0.01	17	0.32	33	1.2	1.100
04/07/2002	D/6	15.3	93	-	8.2	316	100	0.03	18	0.32	32	-	1.080
04/07/2002	E	15.7	93	2.1	8.18	320	100	0.01	16	0.3	38	3.2	1.150
26/03/2003	A/S	9.4	98	1.9	8.19	297	90	<0.01	24	0.46	27	3.2	0.905
26/03/2003	A/6m	9.1	97	-	8.19	298	90	<0.01	26	0.46	31	-	0.960
26/03/2003	B/S	9.6	100	2.4	8.2	296	90	<0.01	23	0.51	25	4	1.066
26/03/2003	B/6m	9.1	98	-	8.2	297	90	<0.01	43	0.46	25	-	1.046
26/03/2003	C/S	9.2	99	2	8.2	298	90	<0.01	23	0.85	28	3.2	0.940
26/03/2003	C/18	7.8	93	-	8.04	310	90	<0.01	25	0.5	31	-	1.057
26/03/2003	D/S	9.1	98	2.2	8.19	299	90	<0.01	24	0.47	25	3.6	1.027
26/03/2003	D/6m	8.4	95	-	8.12	301	90	<0.01	25	0.48	27	-	1.072
26/03/2003	E/S	9.2	100	2.1	8.18	298	90	0.01	24	0.47	25	2.4	1.028
24/07/2003	A/S	18.2	96	3.1	8.36	311	50	<0.01	5	0.16	25	5.2	0.251
24/07/2003	B/S	18.4	97	2.8	8.38	315	50	<0.01	<5	0.16	26	7.3	0.249
24/07/2003	B/6	18.3	98	-	8.39	312	50	<0.01	<5	0.16	44	-	0.239
24/07/2003	C/S	18.4	95	3	8.39	312	50	<0.01	6	0.16	26	8.1	0.223
24/07/2003	C/21 m	18.3	94	-	8.36	312	50	0.02	6	0.16	24	-	0.230
24/07/2003	D/S	18.5	96	3.5	8.4	311	50	0.02	<5	0.14	26	8.1	0.234
24/07/2003	D/5 m	18.3	98	-	8.38	312	50	0.02	<5	0.14	25	-	0.233
24/07/2003	E/S	18.5	94.7	3	8.39	311	50	<0.01	<5	0.15	28	10.9	0.237

Appendix 4 (Contd.): EPA water quality data for Lough Key, 2001

Date Sampled	Station	Temp °C	DO % Sat	Secchi m	pH	Cond µS/cm	Colour Hazen	NH3 mg N	PO4 µg P	TON mg N	TP µg P	Chlorophyll mg/m³	Silica mg Si
11/09/2003	A/S	16.7	91	2.9	8.34	311	50	0.01	<5	0.03	18	4.03	1.022
11/09/2003	B/S	16.7	94	3.2	8.353	310	50	<0.01	<5	0.03	24	4.43	1.012
11/09/2003	B/6M	16.7	94	-	8.36	310	50	<0.01	<5	0.03	26	-	1.001
11/09/2003	C/S	16.7	92	3.2	8.35	311	50	0.01	<5	0.03	14	4.03	1.006
11/09/2003	C/18M	16.6	93	-	8.35	310	50	0.02	<5	0.03	16	-	0.990
11/09/2003	D/S	16.8	93	3.2	8.33	309	50	<0.01	<5	0.02	61	5.6	1.019
11/09/2003	D/6M	16.8	94	-	8.34	309	50	0.02	<5	0.03	34	-	1.028
11/09/2003	E/S	16.9	94	3	8.37	310	50	<0.01	<5	0.02	17	6.45	1.018
11/09/2003	E/6M	17	95	-	8.36	310	50	<0.01	<5	0.02	37	-	1.015
07/10/2003	A/S	13.3	94	3.5	8.3	311	50	0.021	10	0.044	26	4	1.100
07/10/2003	B/S	13.2	94	3.3	8.3	312	40	0.021	9	0.045	23	3.6	1.100
07/10/2003	B/6M	13.3	95	-	8.3	312	40	0.023	11	0.042	37	-	1.100
07/10/2003	C/S	13.2	96	2.5	8.3	314	50	0.025	11	0.046	25	3.6	1.100
07/10/2003	C/18M	13.2	96	-	8.3	312	40	0.025	10	0.044	20	-	1.100
07/10/2003	D/S	13	95.5	-	8.3	313	50	0.023	10	0.044	26	3.6	1.200
07/10/2003	E/S	13.1	93	3.3	8.3	310	40	0.021	10	0.044	24	39.1	1.100
07/10/2003	E/6M	13.1	94	-	8.3	310	40	0.025	9	0.038	23	-	1.100

Appendix 4 (Contd.) Flow and total Phosphorus data for Boyle Sewage Treatment Plant, 2001-

2001 Flow and Total P data

Date	Flow	Total P mg	TP load
9-Jan-01	3645	0.13	473.85
16-Jan-01	2408	0.23	553.84
23-Jan-01	3776	25.76	97269.76
13-Feb-01	2942	0.245	720.79
2-Mar-01	2475	0.28	693
22-Mar-01	2113	0.766	1618.558
4-Apr-01	2899	0.41	1188.59
23-May-01	1777	0.321	570.417
5-Jun-01	1883	3.555	6694.065
19-Jun-01	2349	1.116	2621.484
4-Jul-01	2215	1.246	2759.89
14-Aug-01	2561	0.533	1365.013
10-Sep-01	1802	1.353	2438.106
23-Oct-01	805	1.47	1183.35
20-Nov-01	1289	2.444	3150.316
11-Dec-01	1698	2.332	3959.736
TOTAL	**36637**		**127261**
Mean			**7954**

Flow Data	2001	2002	2003
Mean	2,400	2,700	2,193
Sum	837,519	979,966	528,618
Min	98	81	1309
Max	7,881	8,315	4,424

Note: 2003 data for 9 months only

TP Load/g/day	7.95	2.04	2.77
Weighted P mg	3.47*	0.825	1.22
TP/g/ year	2902	745	1011

*** mean calculated without high value on 23/1/01 is 0.819 mg**

2002 Flow and Total P data

Date	Flow	Total P mg
17-Jan-02	2485	0.257
19-Feb-02	3383	0.203
13-Mar-02	3130	0.139
23-Apr-02	2435	2.071
29-May-02	3950	0.563
19-Jun-02	3140	0.433
19-Jul-02	1819	1.32
1-Aug-02	1818	1.78
17-Sep-02	1177	1.75
16-Oct-02	2099	2.54
25-Nov-02	2119	0.09
11-Dec-02	2128	0.41
TOTAL	**29683**	
Mean		

2003 Flow and Total P data

Date	Flow	Total P mg
22-Jan-03	2628	0.52
24-Feb-03	2528	1.27
12-Mar-03	3855	0.21
29-Apr-03	2737	4.465
28-May-03	2422	0.2
25-Jun-03	1759	1.452
22-Jul-03	1711	0.52
18-Aug-03	1772	1.55
3-Sep-03	1329	2.09
15-Oct-03	1877	0.35
27-Nov-03	2782	nd
9-Dec-03	2196	nd
TOTAL	**22618**	
Mean		

Appendix 4 (Contd.): Water quality data, Boyle River (Drum Bridge) d/s Boyle STP, 2001-200

Sample Date	Temp ºC	DO % Sat	pH	Cond µS/cm	Colour Hazen	NH3 mg N	BOD mg O^2	TON mg N	Nitrite mg N	PO4 mg	TP mg P	SS mg
21/02/2001	6.0	95.9	7.87	320	115	0.033	1.3	0.625	0.010	0.017	0.042	2.8
25/04/2001	10.3	94.6	8.19	358	84	0.021	1.3	0.294	0.006	0.004	0.034	8.0
12/06/2001	14.4	96.5	7.96	381	48	0.018	1.3	0.072	0.004	0.005	0.024	1.0
19/07/2001	16.3	94.6	7.93	353	88	0.012	1.2	0.065	0.003	0.005	0.031	4.0
30/08/2001	-	-	7.77	359	98	0.034	1.3	0.192	0.014	0.013	0.032	4.3
27/09/2001	-	-	7.98	392	71	0.048	1.4	0.236	0.006	0.024	0.057	0.6
18/10/2001	-	-	7.78	315	112	0.043	1.7	0.312	0.012	0.022	0.045	4.3
15/11/2001	-	-	7.97	376	122	0.025	1.9	0.462	0.017	0.020	0.089	3.0
29/11/2001	9.1	94.9	7.63	227	112	0.022	2.4	0.293	0.006	0.012	0.045	21.3
17/01/2002	6.0	97.2	8.24	366	105	0.032	1.5	0.649	0.012	0.020	0.045	3.3
28/02/2002	4.9	99.1	8.36	296	101	0.019	1.5	0.587	0.008	0.017	0.038	5.0
07/03/2002	6.8	97.8	8.27	314	95	0.022	1.6	0.535	0.008	0.014	0.034	3.0
11/04/2002	10.2	101.6	8.48	351	74	0.028	1.4	0.408	0.006	0.007	0.031	3.0
23/05/2002	13.0	100.4	8.31	328	83	0.025	1.2	0.219	0.006	0.010	0.041	6.3
20/06/2002	15.3	99.4	8.34	338	126	0.028	1.3	0.240	0.011	0.014	0.030	3.6
10/07/2002	15.8	100.9	8.27	337	126	0.022	1.4	0.233	0.010	0.015	0.039	1.6
15/08/2002	16.3	102.6	8.43	357	85	0.017	1.5	0.180	0.007	0.013	0.030	1.0
12/09/2002	15.2	101.1	8.32	382	78	0.021	1.2	0.194	0.004	0.017	0.045	0.6
09/10/2002	12.6	98.8	8.15	349	93	0.047	2.7	0.218	0.008	0.027	0.062	12.6
21/11/2002	7.3	96.5	8.15	272	143	0.040	2.3	0.379	0.011	0.026	0.058	-
18/12/2002	2.6	95.4	8.23	340	144	0.045	-	0.426	0.013	0.023	0.043	5.7
21/01/2003	5.2	99.0	8.12	352	42	0.035	1.3	0.526	0.013	0.025	0.050	2.7
18/02/2003	3.4	101.5	8.18	441	100	0.020	1.4	0.535	0.009	0.017	0.041	5.3
26/03/2003	9.3	102.5	8.23	350	101	0.027	1.2	0.461	0.006	0.014	0.030	1.0
15/05/2003	11.4	109.8	8.41	409	55	0.043	1.8	0.202	0.004	0.018	0.034	1.6
12/06/2003	14.5	106.8	7.93	364	130	0.017	1.6	0.215	0.006	0.009	0.033	2.0
10/07/2003	16.7	102.1	8.01	415	72	0.019	1.8	0.171	0.006	0.016	0.027	3.3
14/08/2003	18.0	101.2	7.87	396	57	0.020	1.3	0.069	0.002	0.013	0.028	1.3
24/09/2003	11.7	99.7	7.82	399	39	0.011	1.3	0.023	0.003	0.003	0.027	2.3
16/10/2003	10.1	97.9	-	385	38	0.012	1.0	0.049	0.002	0.002	0.018	2.0

Appendix 4 (Contd.) Water quality data, Boyle River (Br Boyle Abbey) u/s Boyle STP, 2001-200

Sample Date	Temp °C	DO % Sat	pH	Cond µS/cm	Colour Hazen	NH3 mg N	BOD mg O^2	TON mg N	Nitrite mg N	PO4 mg	TP mg P	S m
21/02/2001	6.0	95.7	7.98	317	119	0.032	1.6	0.614	0.009	0.017	0.040	2.
25/04/2001	10.6	99.2	8.21	355	86	0.016	1.4	0.305	0.007	0.001	0.031	1.
12/06/2001	15.0	107.1	8.23	375	55	0.010	1.4	0.041	0.004	0.003	0.020	1.
19/07/2001	16.1	101.6	8.11	352	68	0.013	1.1	0.056	0.003	0.003	0.030	0.
30/08/2001	-	-	7.75	357	79	0.038	1.3	0.159	0.015	0.011	0.022	3.
27/09/2001	-	-	7.96	376	70	0.014	0.9	0.204	0.007	0.008	0.031	0.
18/10/2001	-	-	8.05	320	120	0.035	1.4	0.294	0.013	0.017	0.040	1.
15/11/2001	-	-	7.99	374	126	0.031	1.9	0.449	0.017	0.019	0.035	4.
17/01/2002	6.0	96.5	8.27	371	111	0.033	1.5	0.616	0.013	0.020	0.044	4.
28/02/2002	4.8	99.0	8.33	296	103	0.018	1.4	0.584	0.008	0.016	0.040	4.
07/03/2002	6.8	98.7	8.29	313	96	0.020	1.5	0.532	0.008	0.013	0.034	3.
11/04/2002	10.3	102.7	8.48	345	71	0.010	1.2	0.403	0.005	0.005	0.024	2.
23/05/2002	13.0	99.6	8.32	330	83	0.022	1.4	0.206	0.006	0.008	0.030	7.
20/06/2002	15.3	97.6	8.31	333	132	0.031	1.4	0.227	0.011	0.014	0.034	2.
10/07/2002	16.0	101.2	8.31	333	129	0.025	1.6	0.210	0.010	0.014	0.043	3.
15/08/2002	16.8	103.2	8.48	360	85	0.012	1.2	0.151	0.007	0.011	0.027	0.
12/09/2002	15.8	107.0	8.51	373	70	0.011	1.0	0.086	0.004	0.004	0.039	0.
09/10/2002	12.8	97.8	8.20	372	72	0.016	2.2	0.132	0.004	0.010	0.031	1.
21/11/2002	7.2	96.9	8.13	306	140	0.041	2.4	0.367	0.012	0.026	0.057	-
18/12/2002	2.6	92.0	8.33	342	139	0.094	-	0.428	0.012	0.023	0.045	3.
21/01/2003	5.2	98.5	8.11	357	84	0.031	1.6	0.502	0.011	0.023	0.045	3.
18/02/2003	3.3	101.1	8.19	371	102	0.025	2.7	0.528	0.009	0.016	0.028	-
26/03/2003	9.2	100.4	8.18	343	103	0.014	1.3	0.463	0.006	0.011	0.031	0.
15/05/2003	11.5	110.5	8.56	397	54	0.008	1.6	0.200	0.003	0.004	0.017	3.
12/06/2003	14.5	104.6	7.89	367	122	0.021	1.6	0.203	0.006	0.009	0.023	1.
10/07/2003	18.3	104.9	8.36	379	71	0.017	2.1	0.134	0.006	0.008	0.036	4.
14/08/2003	18.8	100.3	7.87	399	62	0.014	1.5	0.006	0.002	0.001	0.017	0.
24/09/2003	12.5	103.4	7.84	378	41	0.068	0.7	0.157	0.004	0.013	0.016	1.
16/10/2003	10.6	101.6		372	50	0.007	1.1	0.019	0.002	0.001	0.029	1.

Appendix 5: Larva/Veliger Densities (2000-2003)

2000

Date	Site A	Site B	Site C	Site D	Site E
30-Jun-00	11.49	3.62	NS	2.18	9.53
07-Jul-00	2.98	5.75	1.56	0.94	0.03
14-Jul-00	1.14	0.58	2.69	0.54	0.72
21-Jul-00	0.04	4.04	7.71	0.65	NS
28-Jul-00	6.96	16.74	10.81	2.37	7.35
04-Aug-00	2.95	19.78	2.78	1.96	6.05
11-Aug-00	1.67	1.65	1.89	1.75	2.27
18-Aug-00	2.08	1.70	1.68	0.67	2.55
25-Aug-00	0.09	0.51	0.65	0.09	0.61
02-Sep-00	0.28	0.41	0.47	0.26	0.45
07-Sep-00	0.13	0.25	0.23	NS	0.25
16-Sep-00	0.08	0.05	0.03	0.08	0.06

2001

Date	Site A	Site B	Site C	Site D	Site E
10-Jun-01	0.00	0.11	0/07	0.02	0.02
23-Jun-01	0.11	0.07	0.33	0.30	0.07
30-Jun-01	0.89	0.11	1.25	0.35	0.28
06-Jul-01	8.18	7.90	6.69	0.04	3.65
15-Jul-01	2.80	0.58	3.37	0.16	0.73
21-Jul-01	5.04	0.21	0.61	0.30	0.68
28-Jul-01	2.71	16.81	2.97	0.80	2.71
03-Aug-01	3.37	5.68	4.31	2.50	4.88
11-Aug-01	5.77	3.70	4.10	0.30	2.52
18-Aug-01	0.70	1.98	2.26	0.23	3.75
24-Aug-01	0.16	0.00	0.02	0.02	0.07

Appendix 5 (Contd.): Larva/Veliger Densities (2000-2003)

2002

Date	Site A	Site B	Site C	Site D	Site E
12-Jun-02	0.14	0.05	0.02	0.13	ND
18-Jun-02	ND	0.16	0.18	0.08	ND
28-Jun-02	2.38	0.26	0.57	0.69	ND
06-Jul-02	5.17	0.82	4.17	0.24	6.87
13-Jul-02	39.40	2.85	3.02	0.16	4.67
21-Jul-02	12.40	24.86	12.74	3.08	11.39
28-Jul-02	6.23	8.76	8.66	1.73	9.51
04-Aug-02	2.74	8.74	15.26	2.25	ND
13-Aug-02	5.51	0.28	0.56	0.57	11.46
18-Aug-02	4.94	2.81	0.99	0.20	ND
23-Aug-02	9.70	2.72	5.83	0.94	1.99
31-Aug-02	0.46	1.14	1.93	0.08	1.18
12-Sep-02	0.42	0.49	0.26	0.00	0.03
01-Oct-02	0.18	0.05	0.10	0.06	0.00

2003

Date	Site A	Site B	Site C	Site D	Site E
15-Jun-03	0.64	0.51	0.28	0.21	0.71
30-Jun-03	1.48	1.61	1.12	1.53	1.68
07-Jul-03	4.42	1.29	2.82	0.19	5.97
14-Jul-03	3.62	4.14	0.46	0.31	11.68
22-Jul-03	6.61	2.09	8.76	0.26	2.74
29-Jul-03	4.44	1.18	3.76	1.53	6.87
05-Aug-03	3.55	7.78	0.61	0.92	10.12
12-Aug-03	13.87	18.34	45.18	1.49	11.29
19-Aug-03	2.88	0.92	0.35	0.06	13.04
26-Aug-03	0.43	1.60	0.67	0.28	1.86
02-Sep-03	1.25	5.74	7.50	0.09	0.94
11-Sep-03	1.88	0.35	2.37	ND	0.89
20-Sep-03	1.27	2.23	5.17	0.01	0.69
11-Oct-03	0.20	0.09	0.04	0.12	0.11
26-Oct-03	0.04	ND	0.05	0.00	ND

Appendix 6: Veliger Size Distribution, Site B (2000-2003)

	Week 1				Week 2				Week 3				Week 4				W	
Veliger length (um)	**07/07/00**	**06/07/01**	**06/07/02**	**07/07/03**	**14/07/00**	**15/07/01**	**13/07/02**	**14/07/03**	**21/07/00**	**21/07/01**	**21/07/02**	**22/07/03**	**28/07/00**	**28/07/01**	**28/07/02**	**29/07/03**	**04/08/00**	**03/08/0**
70	-	-	-	0	-	-	-	0	-	-	-	1	2	-	-	7	0	-
80	-	-	-	0	-	-	-	2	-	-	-	1	3	1	-	7	4	2
90	3	5	-	2	2	5	1	24	14	2	-	8	10	14	-	25	16	7
100	6	20	30	13	3	7	29	75	47	2	8	25	39	29	9	27	30	29
110	29	11	66	24	11	2	52	38	38	2	19	29	32	9	36	25	23	10
120	41	25	23	33	11	4	13	2	27	1	25	24	46	37	22	16	23	5
130	25	23	10	23	9	2	20	0	9	0	12	10	18	10	12	10	23	9
140	7	18	15	17	4	3	20	2	7	0	26	13	20	20	8	7	19	18
150	9	18	1	19	6	1	15	1	10	-	24	23	17	13	10	6	20	18
160	15	9	2	11	11	0	5	4	13	-	18	10	14	6	6	4	15	6
170	7	4	-	3	12	1	7	0	12	-	2	4	11	2	6	3	14	9
180	5	7	-	3	4	-	5	0	6	-	2	1	7	4	8	1	5	1
190	3	0	-	1	5	-	2	1	8	-	4	0	6	1	17	1	6	11
200	1	6	-	1	-	-	1	1	3	-	4	1	6	2	7	0	5	5
210	-	3	-	-	-	-	-	-	1	-	4	-	5	1	3	2	3	7
220	-	4	-	-	-	-	-	-	0	-	1	-	1	-	3	6	4	4
230	-	2	-	-	-	-	-	-	0	-	1	-	1	-	2	2	4	1
240	-	-	-	-	-	-	-	-	1	-	1	-	0	-	-	1	1	2
250	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	1	3
260	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1

Appendix 6 (Contd.): Veliger Size Distribution, Site B (2000-2003)

	Week 6				Week 7				Week 8			Week 9		Week 10	
Veliger length (um)	**11/08/00**	**11/08/01**	**13/08/02**	**12/08/03**	**18/08/00**	**18/08/01**	**18/08/02**	**19/08/03**	**25/08/00**	**24/08/02**	**26/08/03**	**31/08/02**	**02/09/03**	**12/09/02**	**11/09/03**
70	0	-	-	0	0	-	-	1	0	-	10	-	3	-	3
80	3	-	-	2	1	-	-	0	1	-	22	-	6	-	3
90	9	2	-	6	3	4	-	6	5	1	47	-	17	-	4
100	31	3	2	11	12	8	18	9	2	16	32	8	39	-	14
110	17	15	4	18	19	7	13	15	6	38	10	11	47	5	33
120	8	10	1	29	24	4	19	15	3	14	5	13	23	10	15
130	5	9	0	25	17	6	17	16	11	8	5	9	8	6	13
140	10	12	1	15	11	5	12	19	9	5	4	9	3	3	11
150	28	20	8	6	13	9	11	19	3	14	2	21	1	4	15
160	31	18	2	6	21	6	9	15	1	12	4	20	0	5	16
170	18	11	2	2	27	8	19	15	-	9	3	15	0	4	12
180	13	10	2	7	16	5	16	3	-	3	2	12	0	4	5
190	14	1	1	4	15	2	5	6	-	2	3	4	2	5	1
200	10	3	5	3	8	10	3	6	-	3	1	6	-	5	2
210	9	-	1	6	6	5	1	3	-	8	-	2	-	4	1
220	3	-	1	6	2	3	5	0	-	9	-	5	-	4	1
230	3	-	3	3	4	2	2	1	-	6	-	5	-	2	0
240	-	-	1	0	1	-	3	0	-	4	-	4	-	1	0
250	-	-	1	1	-	-	-	1	-	-	-	1	-	-	1
260	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-

Appendix 6 (Contd.): Veliger Size Distribution, Site C (2000-2003)

	Week 1				Week 2				Week 3				Week 4				W	
Veliger length (um)	07/07/00	06/07/01	06/07/02	07/07/03	14/07/00	15/07/01	13/07/02	14/07/03	21/07/00	21/07/01	21/07/02	22/07/03	28/07/00	28/07/01	28/07/02	29/07/03	04/08/00	03/08/01
70	1	-	-	_	-	-	-	1	-	-	-	-	6	-	-	2	-	-
80	2	1	-	-	-	1	-	3	-	1	-	-	3	1	-	0	5	7
90	6	11	-	1	2	5	-	8	6	7	-	4	14	7	-	10	9	18
100	36	15	20	11	23	23	19	48	28	9	8	21	36	27	5	19	12	7
110	36	12	61	24	34	13	37	35	36	3	45	46	25	8	36	31	17	8
120	20	20	26	28	31	10	9	3	51	2	27	20	21	24	26	12	14	3
130	16	15	16	28	25	4	11	3	26	1	10	6	14	15	16	15	4	7
140	9	19	23	20	28	3	30	4	16	2	13	7	16	22	14	13	16	12
150	6	22	17	18	19	9	19	6	13	0	20	14	12	11	9	8	17	7
160	6	12	2	10	10	7	19	13	9	0	11	14	15	3	11	10	27	4
170	4	7	2	2	4	6	8	10	6	0	5	9	7	2	10	3	17	16
180	1	6	1	4	2	11	5	8	9	1	2	3	10	1	7	6	10	3
190	3	0	-	2	2	1	10	5	5	-	2	0	4	0	9	1	12	11
200	-	4	-	2	3	12	3	2	8	-	2	1	7	3	4	3	18	9
210	-	3	-	-	1	6	-	1	1	-	1	1	6	0	2	2	9	9
220	-	3	-	-	-	9	-	-	3	-	3	0	2	0	2	6	-	4
230	-	2	-	-	-	2	-	-	1	-	1	3	2	0	1	7	-	5
240	-	1	-	-	-	1	-	-	1	-	0	1	0	0	-	2	-	4
250	-	-	-	-	-	3	-	-	1	-	1	-	2	1	-	-	-	2
260	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 6 (Contd.): Veliger Size Distribution, Site C (2000-2003)

	Week 6				Week 7				Week 8			Week 9		Week 10	
Veliger length (um)	**11/08/00**	**11/08/01**	**13/08/02**	**12/08/03**	**18/08/00**	**18/08/01**	**18/08/02**	**19/08/03**	**25/08/00**	**24/08/02**	**26/08/03**	**31/08/02**	**02/09/03**	**12/09/02**	**11/09/03**
70	0	-	-	0	0	-	-	1	0	-	10	-	3	-	3
80	3	-	-	2	1	-	-	0	1	-	22	-	6	-	3
90	9	2	-	6	3	4	-	6	5	1	47	-	17	-	4
100	31	3	2	11	12	8	18	9	2	16	32	8	39	-	14
110	17	15	4	18	19	7	13	15	6	38	10	11	47	5	33
120	8	10	1	29	24	4	19	15	3	14	5	13	23	10	15
130	5	9	0	25	17	6	17	16	11	8	5	9	8	6	13
140	10	12	1	15	11	5	12	19	9	5	4	9	3	3	11
150	28	20	8	6	13	9	11	19	3	14	2	21	1	4	15
160	31	18	2	6	21	6	9	15	1	12	4	20	0	5	16
170	18	11	2	2	27	8	19	15	-	9	3	15	0	4	12
180	13	10	2	7	16	5	16	3	-	3	2	12	0	4	5
190	14	1	1	4	15	2	5	6	-	2	3	4	2	5	1
200	10	3	5	3	8	10	3	6	-	3	1	6	-	5	2
210	9	-	1	6	6	5	1	3	-	8	-	2	-	4	1
220	3	-	1	6	2	3	5	0	-	9	-	5	-	4	1
230	3	-	3	3	4	2	2	1	-	6	-	5	-	2	0
240	-	-	1	0	1	-	3	0	-	4	-	4	-	1	0
250	-	-	1	1	-	-	-	1	-	-	-	1	-	-	1
260	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-

Appendix 6 (Contd.): Veliger Size Distribution, Site E (2000-2003)

	Week 1				Week 2				Week 3			Week 4					
Veliger length (um)	07/07/00	06/07/01	06/07/02	07/07/03	14/07/00	15/07/01	13/07/02	14/07/03	21/07/01	21/07/02	22/07/03	28/07/00	28/07/01	28/07/02	29/07/03	04/08/00	03/08/01
70	-	0	0	0	-	0	0	0	0	0	0	-	1	0	24	-	0
80	-	0	0	0	-	0	0	3	1	0	2	-	1	0	33	3	2
90	-	16	0	4	-	1	0	21	7	0	8	2	15	1	44	2	10
100	1	28	24	26	14	2	44	58	7	26	19	3	47	14	26	2	50
110	-	15	65	27	16	0	58	45	2	48	43	10	7	40	14	1	20
120	-	19	20	28	15	1	18	6	2	16	16	11	19	16	2	5	20
130	-	5	13	27	13	0	15	3	1	15	5	9	3	11	2	1	10
140	-	12	21	16	7	2	11	0	1	13	19	2	10	9	1	12	6
150	2	13	9	7	4	5	5	4	2	13	19	13	7	10	2	4	7
160	2	5	1	5	12	4	1	0	1	5	10	5	4	6	0	7	8
170	1	1	1	5	5	2	1	4	0	2	4	22	0	10	0	13	4
180	-	3	0	1	2	4	1	3	0	1	2	20	1	7	0	10	2
190	-	1	0	1	1	2	2	2	0	3	1	8	-	11	1	15	0
200	-	2	1	2	0	3	2	0	0	2	1	18	-	4	0	9	3
210	-	1	-	1	1	3	-	1	1	1	0	27	-	0	0	11	4
220	-	2	-	-	-	1	-	-	-	2	0	14	-	7	1	24	1
230	-	0	-	-	-	0	-	-	-	3	1	22	-	1	-	17	0
240	-	1	-	-	-	-	-	-	-	-	-	9	-	1	-	16	1
250	-	1	-	-	-	-	-	-	-	-	-	19	-	1	-	20	0
260	-	-	-	-	-	-	-	-	-	-	-	16	-	1	-	23	-
270	-	-	-	-	-	-	-	-	-	-	-	18	-	-	-	14	-
280	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	6	-

Appendix 6 (Contd.): Veliger Size Distribution, Site E (2000-2003)

	Week 6				Week 7				Week 8			Week 9		Week 10	
Veliger length (um)	**11/08/00**	**11/08/01**	**13/08/02**	**12/08/03**	**18/08/00**	**18/08/01**	**18/08/02**	**19/08/03**	**25/08/00**	**24/08/02**	**26/08/03**	**31/08/02**	**02/09/03**	**12/09/02**	**11/09/03**
70	0	-	-	0	0	-	-	1	0	-	10	-	3	-	3
80	3	-	-	2	1	-	-	0	1	-	22	-	6	-	3
90	9	2	-	6	3	4	-	6	5	1	47	-	17	-	4
100	31	3	2	11	12	8	18	9	2	16	32	8	39	-	14
110	17	15	4	18	19	7	13	15	6	38	10	11	47	5	33
120	8	10	1	29	24	4	19	15	3	14	5	13	23	10	15
130	5	9	0	25	17	6	17	16	11	8	5	9	8	6	13
140	10	12	1	15	11	5	12	19	9	5	4	9	3	3	11
150	28	20	8	6	13	9	11	19	3	14	2	21	1	4	15
160	31	18	2	6	21	6	9	15	1	12	4	20	0	5	16
170	18	11	2	2	27	8	19	15	-	9	3	15	0	4	12
180	13	10	2	7	16	5	16	3	-	3	2	12	0	4	5
190	14	1	1	4	15	2	5	6	-	2	3	4	2	5	1
200	10	3	5	3	8	10	3	6	-	3	1	6	-	5	2
210	9	-	1	6	6	5	1	3	-	8	-	2	-	4	1
220	3	-	1	6	2	3	5	0	-	9	-	5	-	4	1
230	3	-	3	3	4	2	2	1	-	6	-	5	-	2	0
240	-	-	1	0	1	-	3	0	-	4	-	4	-	1	0
250	-	-	1	1	-	-	-	1	-	-	-	1	-	-	1
260	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-

Appendix 7: Estimated Zebra Mussel Juvenile Settlement, Summers 2000-2003

Week	Date	Site 1	Site 2	Site 3	Site 4	Site 5
1	23/06/2001	45	0	0	45	0
	28/06/2002	45	45	nd	45	nd
2	06/07/2002	45	0	nd	45	45
	07/07/2003	0	180	0	0	0
3	14/07/2000	0	0	0	0	0
	15/07/2001	710	980	11,500	90	0
	13/07/2002	45	2,340	1,670	45	45
	14/07/2003	90	0	0	0	0
4	21/07/2000	45	450	270	0	0
	21/07/2001	1,330	1,100	25,000	440	265
	21/07/2002	45	45	90	3000	45
	22/07/2003	90	4,300	nd	0	2,670
5	28/07/2000	2,520	2,340	2,610	225	999
	28/07/2001	1,000	4,000	4,500	3,500	2,500
	28/07/2002	90	0	1,670	140	140
	29/07/2003	4,330	3,000	2,000	0	2,330
6	04/08/2000	28,000	86,500	5,000	200	18,500
	03/08/2001	0	1,000	3,500	6,000	2,500
	04/08/2002	2,670	1,670	1,340	340	1,000
	05/08/2003	8,670	4,330	9,000	2,330	7,670
7	11/08/2000	10,000	27,500	24,500	45	10,000
	11/08/2001	6,000	14,000	39,000	11,500	1,500
	13/08/2002	90	4,000	2,335	0	45
	12/08/2003	7,330	15,670	22,670	670	22,670
8	18/08/2000	17,500	16,000	18,000	45	13,000
	18/08/2001	2,500	3,000	18,500	500	7,000
	18/08/2002	45	360	620	45	45
	19/08/2003	4,000	19,670	169,670	4,000	77,330
9	25/08/2000	20,000	22,500	7,000	405	14,500
	24/08/2001	2,000	1,000	5,500	1,000	500
	23/08/2002	360	45	400	90	0
	26/08/2003	2,000	9,670	2,000	1,670	8,330
10	02/09/2000	15,000	4,000	6,500	45	7,500
	02/09/2001	0	1,000	3,000	1,000	10,500
	31/08/2002	0	140	220	0	45
	02/09/2003	670	1,000	330	330	3,300
11	08/09/2001	2,500	500	2,000	0	4,500
	12/09/2002	0	1,670	nd	45	175
	09/09/2003	1,330	2,000	7,000	1,000	4,000
12	16/09/2000	5,500	8,000	900	135	3,000
	20/09/2001	0	500	0	0	1,000
	19/09/2002	0	140	220	0	45
	21/09/2003	no data	1,330	330	1,330	1,330
13	01/10/2000	3,500	6,000	2,000	45	8,000
	30/09/2001	0	90	0	0	0
	01/10/2002	1,000	0	1,000	0	0
	11/10/2003	nd	1,330	1330	0	1,670

Appendix 8: Snorkel Sites 2003

Site 1: Drummons Bay **GPS: IG8417 0426** Date: 10/08/03

Depth: 1 metre Temp: 23.0°C

No stones at this site

Substrate	% Substrate	%zm cover
Stone	0	0
Mud	100	0
Peat	0	0
Anodonta	<1	100
Other	0	0

Plants	1	2	3	4	5	6	7	8	9	10
Old *P. australis*	10	3	6	4	3	16	3	0	<1	2
New *P. australis*	0	0	<1	0	0	0	0	0	0	0
S. lacustris	0	<1	0	0	0	0	0	0	0	<1

Anodonta				
Density (m^2)	% Alive	% Dead	% zm cover	No.
<1	0	100	100	30

Anodonta have dropped below the surface and only a small portion of some remain exposed above the surface

Appendix 8 (Contd.): Snorkel Sites 2003

Site 2: Drumbridge Bay at Crannog

GPS IG 8232 0412

Date: 08/08/03

Temp:24.7°C

Depth: 1.2 metre

Substrate	% Substrate	%zm cover
Stone	75	50
Mud	25	0
Peat	0	0
Anodonta	<1	80
Other	0	0

Stone

25 x 25cm2 quadrat has a zm biomass of 143 grams
25 x 25 cm^2 quadrat has a zm biomass of 306 grams
25 x 25cm^2 quadrat has a zm biomass of 167 grams

Mean zm biomass = 205 grams

Stones from 0.5 metre depth

Plants	1	2	3	4	5	6	7	8	9	10
Old *P. australis*	0	0	0	0	0	0	0	0	0	0
New *P. australis*	0	0	0	0	0	0	0	0	0	0
S. lacustris	0	0	0	<1	0	0	0	0	0	0

Anodonta

Density (m^2)	% Alive	% Dead	% zm cover	No.
3	0	100	80	30

Appendix 8 (Contd.): Snorkel Sites 2003

Site 3: Church Island

Date: 11/08/03

Depth: 0.5 - 3.0 metres

Substrate	% Substrate	%zm cover
Stone	40	50
Rock	20	50
Mud	40	0
Peat	0	0
Anodonta	<1	100
Other	0	0

Stone

25x25 cm^2 quadrat on stones has a zm biomass of 166 grams
25x25 cm^2 quadrat on stones has a zm biomass of 210 grams
25x25 cm^2 quadrat on stones has a zm biomass of 231 grams

Mean zm biomass = 202g

Plants	1	2	3	4	5	6	7	8	9	10	Densi
S. lacustris	<1	0	0	0	0	0	0	0	0	0	

No *P. australis* at this site

Anodonta				
Density (m^2)	% Alive	% Dead	% zm cover	No.
4	0	100	100	30

Appendix 8 (Contd.): Snorkel Sites 2003

Site 4: Stag Island **GPS: IG82267 06961** **Date: 12/08/03**

Depth: 2.0 metres Distance from Shore: 8 metres

Substrate	% Substrate	%zm cover
Stone	10	80
Boulder	0	0
Rock	0	0
Mud	90	0
Peat	0	0
Anodonta	5	100
Other	0	0

Stone

25 x 25 cm^2 quadrat has a zm biomass of 592 grams
25 x 25 cm^2 quadrat has a zm biomass of 331 grams
25 x 25 cm^2 quadrat has a zm biomass of 269 grams

Mean zm biomass = 397 grams

Plants	1	2	3	4	5	6	7	8	9	10	Den
Old *P. australis*	<1	<1	0	7	0	1	8	1	1	3	
New *P. australis*	0	0	0	0	0	0	0	0	0	0	
S. lacustris	0	0	0	0	0	0	0	0	0	<1	

Anodonta				
Density (m^2)	% Alive	% Dead	% zm cover	No.
3	0	100	100	30

Appendix 8 (Contd.): Snorkel Sites 2003

Site 5: Hermit Island **GPS IG 8368 0600** **Date: 09/08/03**

Depth: 0.5 - 3.0 metres Temp: 21.6°C

Substrate	% Substrate	%zm cover
Stone	20	70
Boulder	40	70
Rock	40	70
Mud	0	0
Peat	0	0
Anodonta	3	100
Other	0	0

Stone

25 x 25 cm^2 quadrat has a zm biomass of 207 grams
25 x 25 cm^2 quadrat has a zm biomass of 244 grams
25 x 25 cm^2 quadrat has a zm biomass of 277 grams

Mean zm biomass = 242 grams

Plants	1	2	3	4	5	6	7	8	9	10	Densi
S. lacustris	0	<1	0	0	0	0	0	0	0	0	

No *P. australis* at this site

Anodonta				
Density (m^2)	% Alive	% Dead	% zm cover	No.
4	0	100	100	30

Appendix 8 (Contd.): Snorkel Sites 2003

Site 6: Bullock Island **GPS: IG84945 05989** Date: 09/08/03

Depth: 1-2 metres Temp: 21.6°C

Substrate	% Substrate	%zm cover
Stone	<5	85
Mud	95	0
Peat	0	0
Anodonta	5-10	100
Other	0	0

Stone

25 x 25 cm^2 quadrat has a zm biomass of 201 grams
25 x 25cm^2 quadrat has a zm biomass of 148 grams
2**5 x 25** cm^2 quadrat has a zm biomass of 253 grams

Mean zm biomass = 201 grams

Plants	1	2	3	4	5	6	7	8	9	1
S. lacustris	0	0	0	0	0	0	0	0	0	(

No *P. australis* at this site, *E fluviatile* present in v. low numbers, also without zm colonisation.

Anodonta				
Density (m^2)	% Alive	% Dead	% zm cover	No.
4-5	0	100	100	30

Appendix 8 (Contd.): Snorkel Sites 2003

Site 7: Green Island

Date: 8/08/03

Temp: 20.6°C

Depth: 1.5 metre

Substrate	% Substrate	%zm cover
Stone	5	50
Mud	25	0
Peat	0	0
Anodonta	<1	100
Rock	70	50

Stone

25 x 25cm^2 quadrat on stones has a zm biomass of 44 grams
25 x 25cm^2 quadrat on stones has a zm biomass of 45 grams
25 x 25cm^2 quadrat on stones has a zm biomass of 93 grams

Mean zm biomass = 61 grams

Plants	1	2	3	4	5	6	7	8	9	10	I
Old *P. australis*	2	6	1	4	4	4	4	4	<1	<1	
New *P. australis*	3	2	1	10	12	0	0	4	12	0	
S. lacustris	0	0	<1	0	0	0	0	0	0	0	

Anodonta				
Density (m^2)	% Alive	% Dead	% zm cover	No.
3	0	100	100	30

Appendix 8 (Contd.): Snorkel Sites 2003

Site 8: Clarendon **GPS: IG86643 05747** **Date: 12/08/03**

Depth: 2.0 metres Temp: 21.4°C

Substrate	% Substrate	%zm cover
Stone	70	100
Rock	20	100
Mud	0	0
Peat	0	0
Anodonta	10	100
Other	0	0

Rock/Cobble/Stones

25 x 25cm^2 quadrat has a zm biomass of 790 grams
25 x 25cm^2 quadrat has a zm biomass of 666 grams
25 x 25cm^2 quadrat has a zm biomass of 706 grams

Mean zm biomass = 721 grams

Plants	1	2	3	4	5	6	7	8	9	10	Density
Old *P. australis*	15	36	48	24	35	20	<1	<1	4	4	10
New *P. australis*	0	2	0	0	0	0	0	0	0	0	25
S. lacustris	0	0	<1	0	0	0	0	0	0	0	60

Anodonta				
Density (m^2)	% Alive	% Dead	% zm cover	No.
3	0	100	100	30

Appendix 9: Transect Sampling Calculations, Lough Key, August, 2002

Total no. of zebra mussels/m^2 along the eight transects in Lough Key, August, 2002

Depth	N	S	E	W	NE	SW	SE	NW
0-1	5728	15856	4000	4048	8176	432	5872	7664
	5392	4992	1312	2672	10736	656	5456	9120
	7792	5008	1712	6352	2128	1584	10944	11072
1-2	10064	15216	12880	6336	1568	512	12656	4208
	8432	10176	7280	3680	8384	544	11552	3040
	9808	15152	1184	5536	20576	0	10560	1728
2-3	11312	8464	11056	7840	4208	448	15776	0
	4832	13024	10096	3296	6736	1872	7936	1392
	6368	10256	11968	7712	7792	1040	13968	1952
3-4	4512	6176	4688	5984	1808	0	6112	560
	3456	3888	2096	3312	2224	0	6096	912
	4352	4112	5984	1856	1472	16	6080	0
4-5	2608	2960	0	0	640	0	2448	0
	4704	5904	240	0	0	0	3696	0
	5472	3920	2920	0	0	0	4736	0
5-6	1728	640	0	0	0	0	528	0
	11648	2280	0	0	0	0	4960	0
	2720	3680	0	80	0	0	0	0
6-7	0	0	0	0	0	0	0	0
	0	1080	0	0	0	0	0	0
	0	0	0	0	0	40	0	0
7-8	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
8-9	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
9-10	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0

Appendix 9 (Contd.): Transect Sampling Calculations, Lough Key, August, 2002

Total no. of zebra mussels/m^2 along the eight transects in Lough Key, August, 2002

Depth	N	S	E	W	NE	SW	SE	NW
10-11	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	720	0	0	0	0
11-12	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
12-13	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
13-14	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
14-15	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
15-16	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
16-17	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
17-18	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
18-19	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
19-20	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0

Total number of zebra mussels in L.Key is 3,959/m^2

Total number of zebra mussels in L.Key below 6 metres is 5,903/m^2

Appendix 9: Transect Sampling Calculations, Lough Key, August, 2002

Total biomass of zebra mussels/m^2 along the eight transects in Lough Key, August, 2002

Depth	N	S	E	W	NE	SW	SE	NW
0-1	1568	3104	992	912	1984	64	1072	832
	1104	1552	352	608	3296	144	752	1040
	2096	832	480	816	672	208	1792	1328
1-2	1456	2064	2640	912	192	160	1344	640
	1408	1152	2528	640	656	112	1104	704
	3040	2336	144	752	1184	0	1408	304
2-3	1040	1024	1200	1312	560	96	1696	0
	528	1584	1072	528	944	336	832	448
	720	1056	1872	1056	1136	176	1488	400
3-4	704	928	784	1440	240	0	672	224
	496	624	352	864	192	0	544	320
	688	640	944	480	160	80	624	0
4-5	704	592	0	0	120	0	224	0
	1040	1168	40	0	0	0	480	0
	1280	848	760	0	20	0	560	0
5-6	368	120	0	0	40	0	80	0
	2368	440	0	0	0	0	592	0
	528	840	0	40	0	0	0	0
6-7	0	0	0	0	0	0	0	0
	0	200	0	0	0	0	0	0
	0	0	0	0	0	20	0	0
7-8	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
8-9	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
9-10	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
10-11	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0

Appendix 9 (Contd.): Transect Sampling Calculations, Lough Key, August, 2002

Total biomass of zebra mussels/m^2 along the eight transects in Lough Key, August, 2002

Depth	N	S	E	W	NE	SW	SE	NW
11-12	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	80	0	0	0	0
12-13	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
13-14	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
14-15	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
15-16	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
16-17	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
17-18	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
18-19	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
19-20	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0

Total biomass of zebra mussels in L.Key is 520 grams/m^2

Total biomass of zebra mussels in L.Key below 6 metres is 764 grams/m^2